SR 108 MP 5.5 Unnamed Tributary to Skookum Creek: Preliminary Hydraulic Design Report

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SR 108 Unnamed Tributary – Remove Fish Barrier
MP 5.5 Unnamed Tributary to Skookum Creek
Preliminary Hydraulic Design Report
July 2020

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1.0 Introduction and Purpose

To comply with United States, et al vs. Washington, et al No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas (WRIAs) 1-23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the SR 108 crossing of Unnamed Tributary to Skookum Creek at Mile Post (MP) 5.5. This existing structure on SR 108 has been identified as a fish barrier by Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (Site ID 991237) due to its steep slope. Per the injunction, and in order of preference, fish passage should be achieved by (a) avoiding the necessity for the roadway to cross the stream, (b) use of a full span bridge, or (c) use of the stream simulation methodology. WSDOT evaluated design options as defined in the injunction. Avoidance of the stream crossing was determined to not be viable given the location of the highway and the need to maintain this critical transportation corridor. WSDOT is proposing to replace the existing crossing structure with a structure designed using the stream simulation culvert design methodology.

The structure is located in Mason County 3.9 miles northeast of McCleary, WA in Water Resource Inventory Area (WRIA) 14. The highway runs east-west at this location, while the Unnamed Tributary generally flows northwest to southeast, beginning approximately 5,000 feet upstream of its crossing with SR 108 and discharging into Skookum Creek directly downstream of its crossing with SR 108. Skookum Creek generally flows west to east and joins the Little Skookum Inlet approximately 6.8 miles downstream of the confluence with the Unnamed Tributary. See Figure 1 for the vicinity map.

The proposed project will replace the existing 85 feet long, 36-inch diameter concrete culvert with a minimum 16 foot span structure to improve fish passage while providing a safe roadway for the traveling public. This proposed structure is designed to meet the requirements of the federal injunction utilizing the culvert design criteria outlined in the 2013 WDFW Water Crossing Design Guidelines (WCDG).

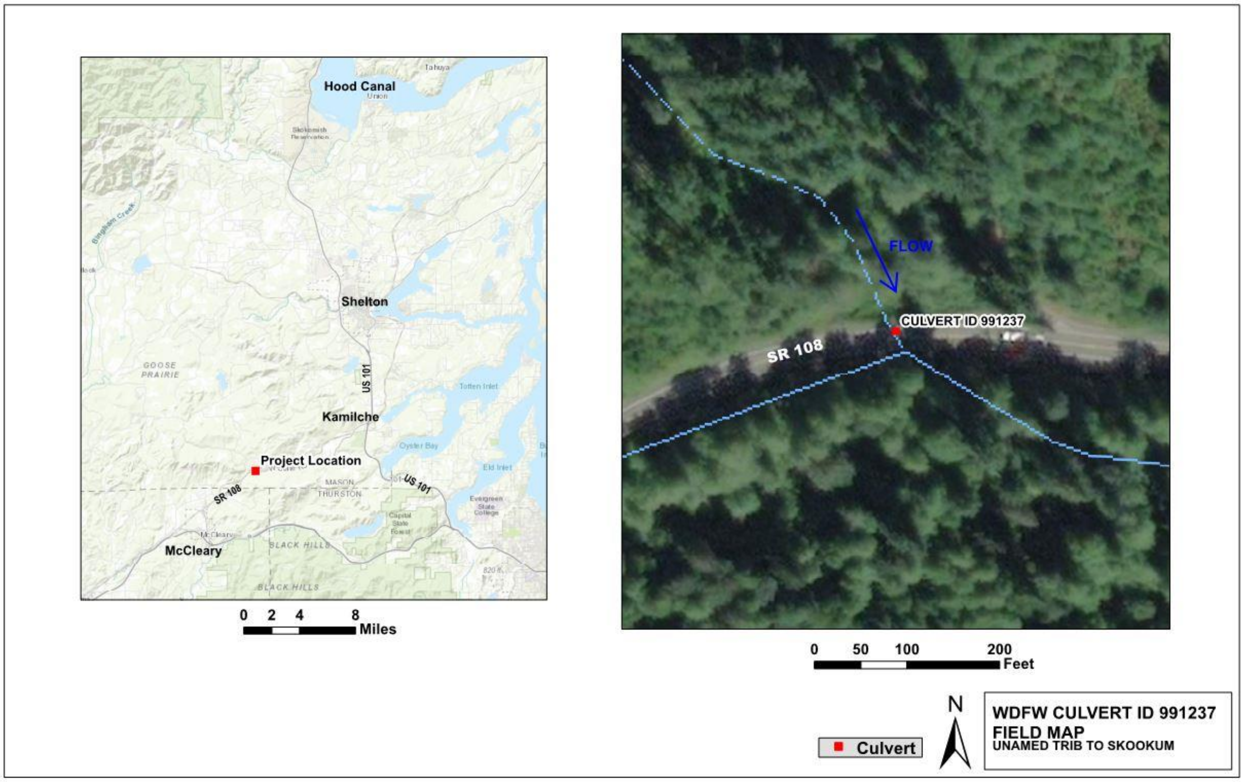


Figure 1 Vicinity map

2.0 Site Assessment

Osborn Consulting, Inc. (OCI) and HDR conducted a site visit on August 23, 2019 to visually assess the stream and collect information to support the design of the Unnamed Tributary to Skookum Creek. The team walked the stream approximately 300 feet upstream and downstream from the existing 36-inch diameter, concrete culvert inlet and outlet, respectively. The following provides a description of field observations moving from upstream to downstream.

Upstream of the existing culvert, the stream flows through a corridor densely vegetated with trees, shrubs, and blackberry that provide significant canopy cover. The upstream reach is slightly incised with bank heights ranging from 1.5 feet to 2.5 feet. The stream channel contains pool and riffle sections with mid-channel sediment bars present throughout the upper end of the observed upstream reach (Figure 2). The streambed substrate appears to be composed of poorly-sorted material including fines, small gravels, and cobbles. The upstream reach contains accumulations of wood and appears to have high potential for wood recruitment.

Figure 2 Typical channel upstream of existing culvert with sediment bar formation

Two bankfull width measurements were taken approximately 150 feet and 250 feet upstream of the existing culvert inlet, which measured 11 feet and 10.8 feet, respectively (Figure 3).

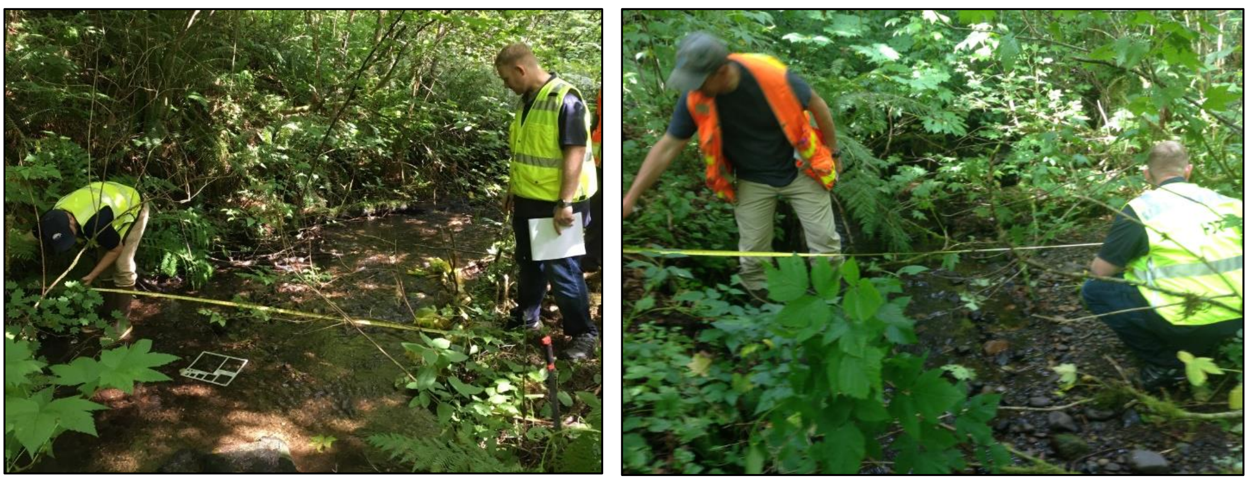


Figure 3 Bankfull width location 150 feet upstream of existing culvert (Left) and 250 feet upstream of existing culvert (Right)

The channel narrows at the culvert inlet (Figure 4). Based on the 2005 WDFW Fish Passage and Diversion Screening Inventory Database (FPDSI) Report, the culvert to stream width ratio is 0.25 and the roadway fill depth is 23 feet.

Figure 4 SR 108 culvert inlet

The culvert outfalls directly into Skookum Creek at a large scour pool (Figure 5). Skookum Creek flows along the roadway embankment upstream of the confluence with the Unnamed Tributary. The Unnamed Tributary enters Skookum Creek on its left bank.

Figure 5 SR 108 Culvert outlet (Left) and scour pool (Right)

The stream corridor from the culvert outlet to approximately 300 feet downstream of the outlet is densely vegetated with large trees and shrubs, and the banks appear to be stable with no major signs of bank erosion. The stream flows through pools and riffles within the channel, and mid-channel sediment bars are present throughout the reach (Figure 6). The streambed substrate is composed of fines, small gravels, and cobbles. The channel contains accumulations of wood and appears to have high potential for further wood recruitment. The channel gradient begins to increase approximately 200 feet downstream of the culvert outlet.

Figure 6 Typical channel downstream of existing culvert

3.0 Watershed Assessment

3.1 Watershed & Landcover

The Unnamed Tributary to Skookum Creek flows in a generally southeasterly direction and joins Skookum Creek at the existing culvert outlet. Skookum Creek drains into the Little Skookum Inlet near Kamilche, which flows into Totten Inlet and eventually into the Puget Sound. The drainage area to the stream at the existing SR 108 culvert crossing is 0.34 square miles delineated based on LiDAR data using GIS ArcHydro tools. The mean annual precipitation is 91.2 inches (PRISM). The Unnamed Tributary enters the mainstem of Skookum Creek on the left bank just downstream of the culvert outlet. The drainage area to the tributary at this confluence is 0.40 square miles, giving a combined drainage area of 0.74 square miles downstream of the confluence.

The basin is primarily comprised of evergreen forest based on ESRI aerial imagery and 2016 NLCD land cover data, with some open space areas due to access roads and smaller pockets of mixed forest and shrub/scrub land throughout. The West Cloquallum Truck Trail bisects the basin, and the Burlington Northern Santa Fe rail line crosses the downstream portion of the basin. Figure 7 shows a map of the basin boundary.

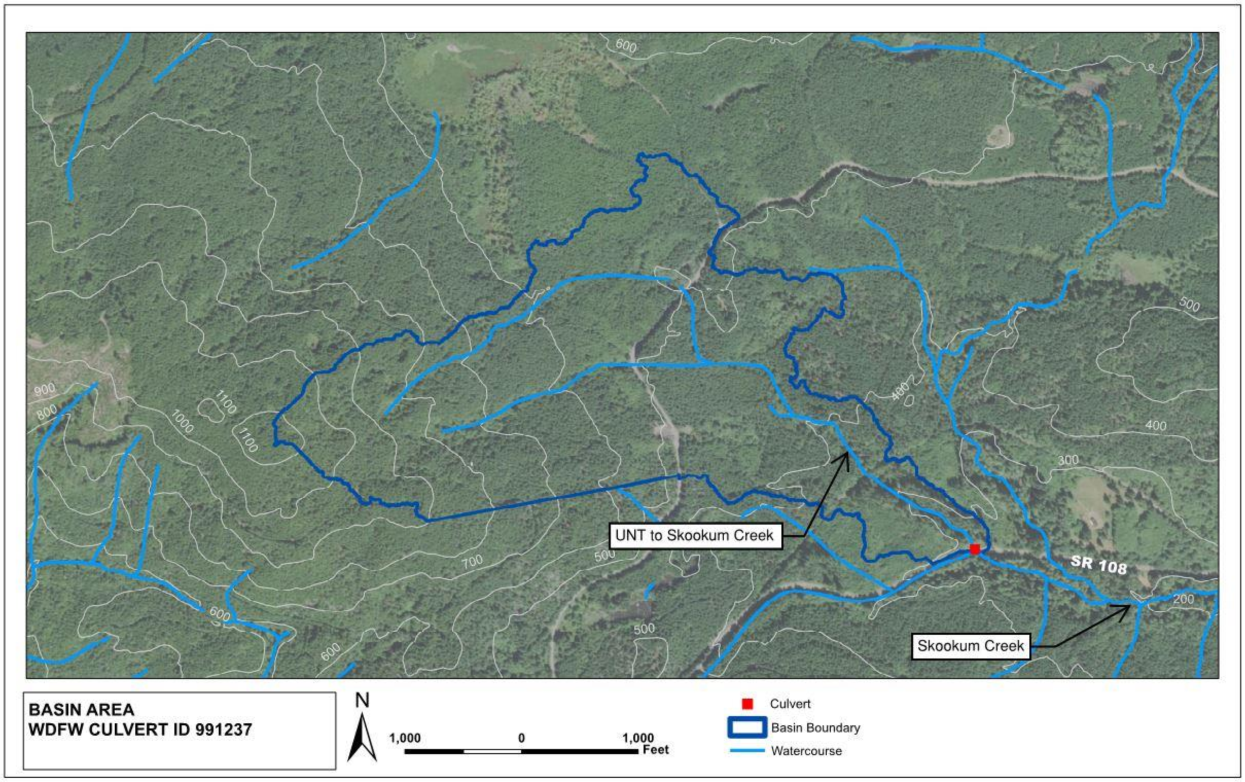


Figure 7 Basin boundary

3.2 Mapped Floodplains

The project site is located at the boundary of the FEMA-mapped Zone A 100 year floodplain of Skookum Creek based on Flood Insurance Rate Map (FIRM) 53045C0750E (Figure 8). The existing SR 108 culvert is located in Zone X, an area of minimal flood hazard, but the proposed downstream end of the Unnamed Tributary channel near the confluence with Skookum Creek will likely fall within the Zone A floodplain. Zone A refers to areas subject to inundation by the 100-year flood event but base flood elevations have not been determined by FEMA.

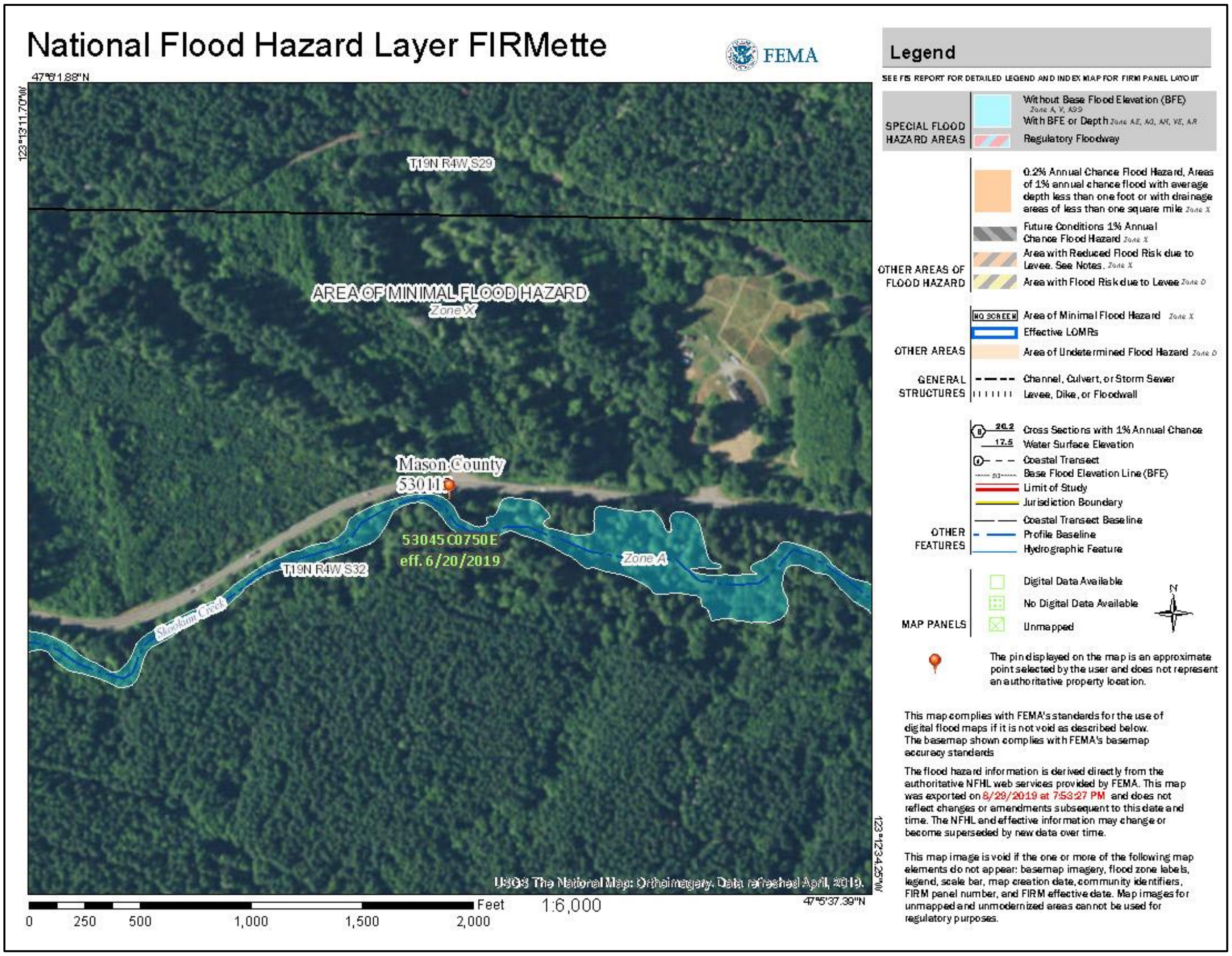


Figure 8 FEMA mapped floodplain (FIRM 53045C0750E)

3.3 Geology & Soils

The drainage basin to the Unnamed Tributary to Skookum Creek is mostly underlain by continental glacial deposits including Vashon Stade outwash and Pre-Fraser Glaciation drift, as well as tertiary igneous rock of the Crescent Formation. The continental glacial deposits typically contain granitic and metamorphic rock and abundant polycrystalline quartz (Logan, 2003). The majority of the basin consists of Vashon Stade proglacial and recessional outwash (Qgo) and Crescent Formation basalt (Ev_c). A small area in the downstream portion of the basin consists of Pre-Fraser Glaciation till and outwash sand and gravel (Qgp) near the confluence with Skookum Creek. Figure 9 shows a map of the geologic units in the basin. These geologic units are further described as follows:

> **(Ev_c) Crescent Formation basalt** – Tertiary igneous rock of lower to middle Eocene period; characterized by dark gray greenish tint, brown where weathered, reddish and variegated along altered contact zones.
>
> **(Qgo) Proglacial and recessional outwash, late Wisconsinan (Pleistocene epoch), Vashon Stade** - Continental glacial deposits of Fraser Glaciation; poorly to moderately sorted, rounded gravel and sand with localized coarser- and finer-grained constituents; typically shades of gray where fresh or brown where stained

(Qgp) Drift - Continental glacial deposits of Pre-Fraser Glaciation; undifferentiated till and outwash sand and gravel of northern provenance; commonly oxidized or stained orange

Elevations within the watershed range between approximately 250 feet to 1150 feet above sea level based on contours obtained from Mason County GIS. The upper (western) portion of the basin has relatively steep slopes of approximately 15-30% or locally greater, and the lower (eastern) portion of the basin has gentler slopes ranging from <1% to approximately 15%.

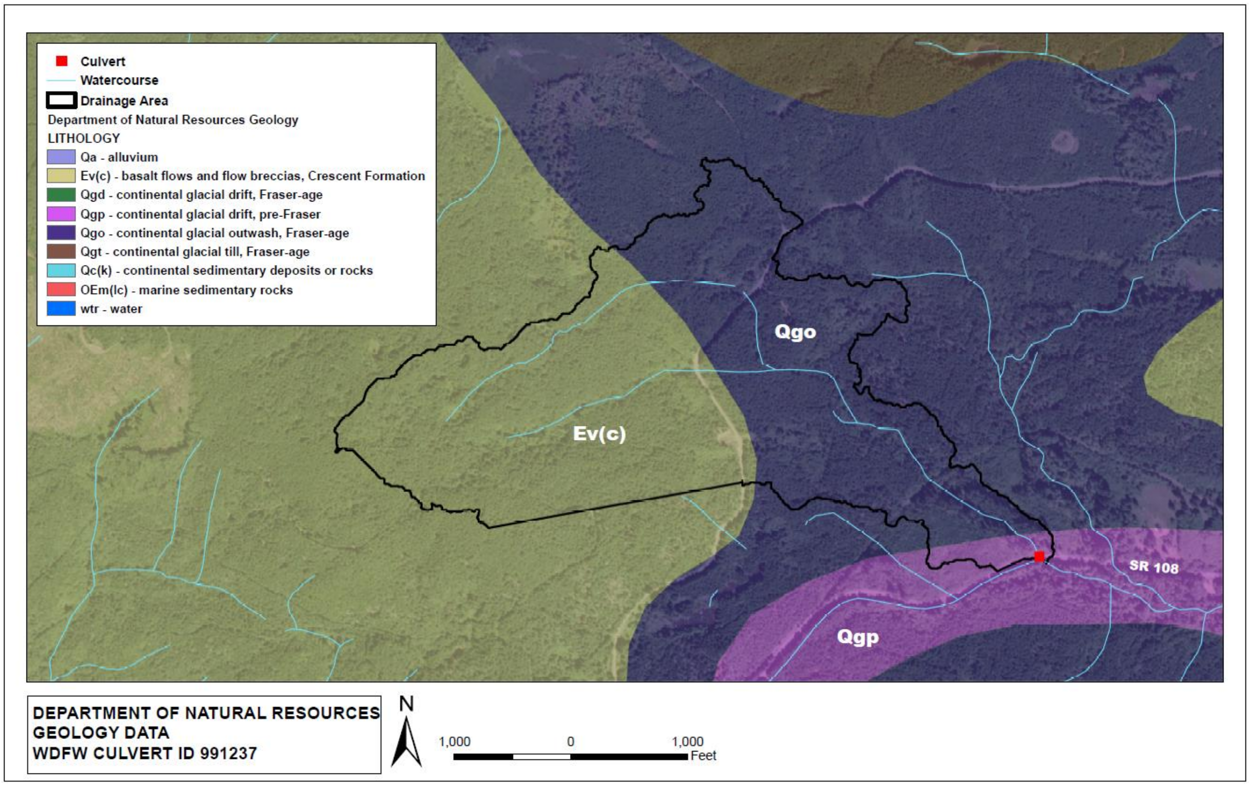
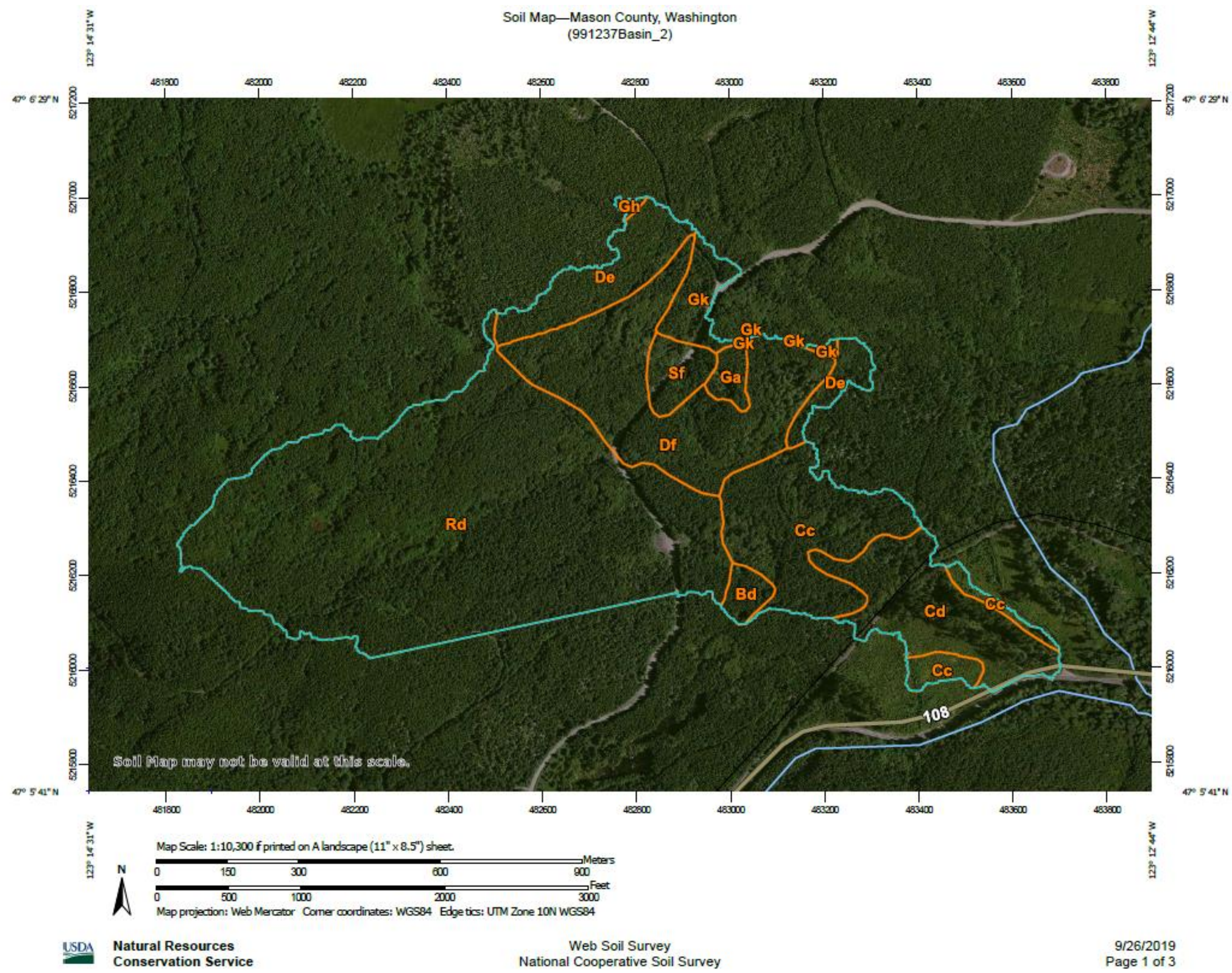


Figure 9 Surficial geology (WA DNR Geologic Units 1:100,000 Scale)

Soils in the basin primarily include silt loam, gravelly sandy loam, gravelly loam, unweathered bedrock, and Tebo soil material. Tebo soil material is described as till derived from basalt consisting of silt loam and gravelly clay loam. The hydrologic soil groups (HSG) of the soils within the basin are approximately 6% A, 48% B, 21% C, and 25% bedrock. These soils vary from well-drained with high infiltration rate (HSG A) to poorly drained with slow infiltration rate (HSG C). Figure 10 shows a map and table of the soil units in the basin.



Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
Bd	Bellingham silt loam, 0 to 3 percent slopes	2.2	1.0%
Cc	Cloquallum silt loam, 5 to 15 percent slopes	25.8	11.8%
Cd	Cloquallum silt loam, 15 to 30 percent slopes	18.7	8.5%
De	Delphi gravelly loam, 5 to 15 percent slopes	14.2	6.5%
Df	Delphi gravelly loam, 15 to 30 percent slopes	34.3	15.7%
Ga	Gravel pit	2.2	1.0%
Gh	Grove gravelly sandy loam, 0 to 5 percent slopes	0.4	0.2%
Gk	Grove gravelly sandy loam, 5 to 15 percent slopes	5.5	2.5%
Rd	Rough mountainous land, Tebo soil material	111.3	50.8%
Sf	Shelton gravelly sandy loam, 5 to 15 percent slopes	4.4	2.0%
Totals for Area of Interest		**218.8**	**100.0%**

Figure 10 NRCS Web Soil Survey

3.4 Geomorphology

3.4.1 Channel Geometry

In the stream channel both upstream and downstream of the existing culvert, riffle-pool morphology is observed with mid-channel sediment bars present throughout (Figure 11). The channel is relatively straight with mild meander bends. Upstream, the stream banks are approximately 1.5 to 2.5 feet high, with slight bank erosion on the right bank. The upstream channel gradient is approximately 4% and appears to further steepen approximately 250 feet upstream of the existing culvert inlet. Approximately 200 feet downstream of the existing culvert outlet there is also a steeper section of stream that exhibits some cascade characteristics.

Figure 11 Channel upstream of existing crossing (left) and channel downstream of existing crossing (right)

It was determined that the upstream reach is the most representative of the natural stream channel Two bankfull width measurements were taken approximately 150 feet and 250 feet upstream of the existing culvert inlet, which measured 11 feet and 10.8 feet, respectively (see photos in Section 2.0).

Bankfull width measurements were not taken downstream of the existing SR 108 crossing because the Unnamed Tributary enters Skookum Creek, just downstream of the culvert outlet. A pool has formed just downstream of the culvert outlet. Due to the added flow input, measurements in the downstream reach would not be representative of the channel geometry moving through the culvert.

Based on the basin area (0.34 square miles) and annual precipitation (91.2 inches per year), the WDFW regression equation estimates a bankfull width to be 9.2 feet.

A long channel profile was developed from the 2019 survey data and 2005 Puget Sound Lowlands LiDAR data (Figure 12). Upstream of the project area, the average reach slope is 5 percent. Within the detailed survey, the reach slope decreases to an average of 4 percent. The reach downstream of the survey becomes even less steep, with an average slope of 3 percent.

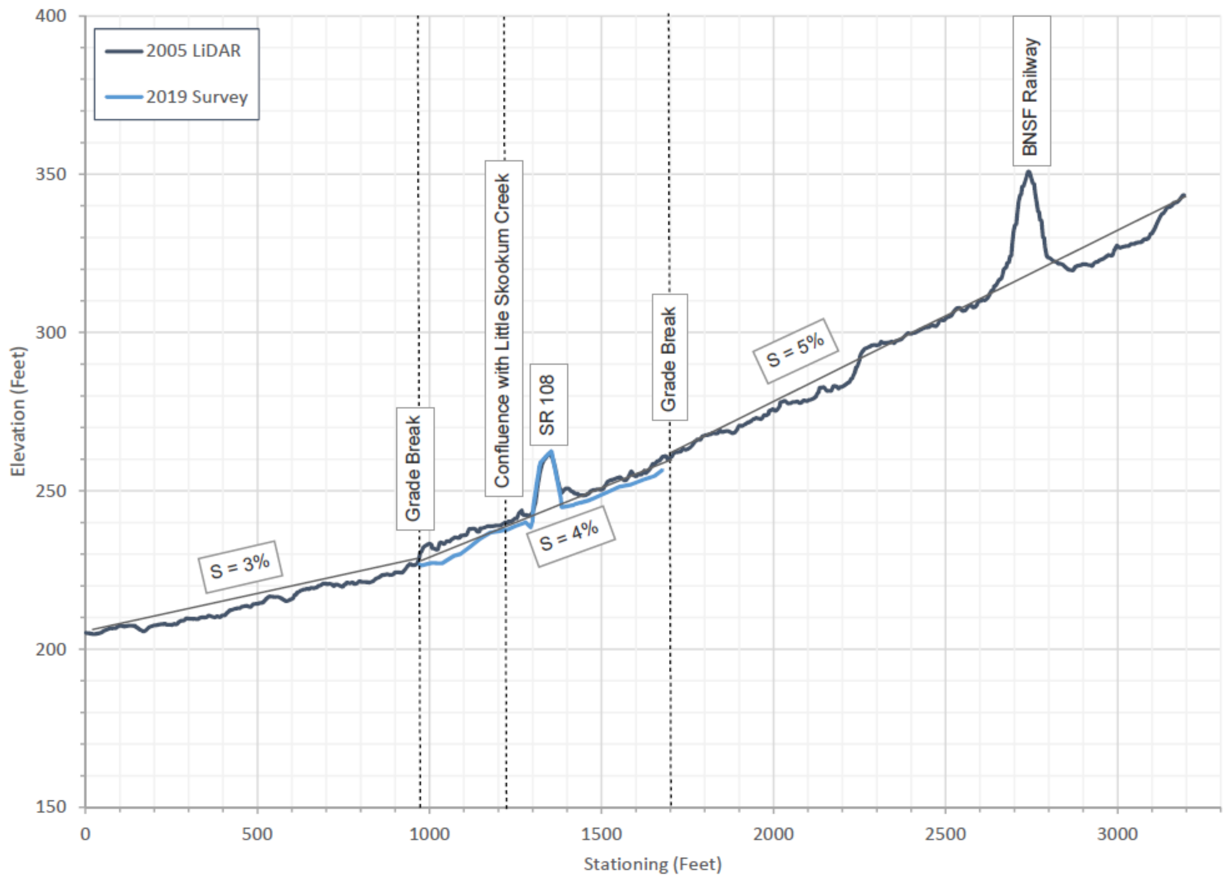


Figure 12 Long profile of UNT near SR 108 crossing

3.4.2 Potential for Aggradation, Incision and Headcutting

The WDFW Site Description Report notes a stream gradient of 4.2 percent. The stream appears to be slightly incised upstream of the existing culvert, with bank heights ranging from 1.5 feet to 2.5 feet with potential for the incision to continue over time. The streambed substrate is poorly sorted with a wide range of sand, small gravel, and cobbles. There does not appear to be any significant signs of aggradation or headcut risk in the assessed portions of the stream.

3.4.3 Floodplain Flow Paths

Slight incision of the stream channel upstream of the existing culvert indicates that storm flows mainly stay within the channel and may overtop the banks only during large storm events. Downstream of the culvert, the stream appears to be well connected to the floodplain; however, the floodplain is narrow and confined by the nearby SR 108 roadway embankment to the left and steep valley walls to the right.

3.4.4 Channel Migration

Opportunity for channel migration is relatively low as the valley walls are steep. Dense vegetation on the banks suggests that the tributary has not experienced significant lateral movement recently and is not expected to expand within the floodplain. The land cover is largely forested, and flows are not expected to change significantly if the basin remains undisturbed.

3.4.5 *Existing LWM and Potential for Recruitment*

In the reaches both upstream and downstream of the existing culvert, the stream contains multiple accumulations of wood within the channel. The riparian corridor is densely vegetated with shrubs and large trees. The stream channel appears to have high potential for further wood recruitment. See Figure 13 for photos of wood accumulation in the channel.

Figure 13 Typical channel downstream of existing culvert with wood accumulation

3.4.6 *Sediment Size Distribution*

The streambed substrate is composed of poorly sorted material including fines, small gravels, and cobbles in the reaches both upstream and downstream of the existing culvert. On August 29, 2019, A Wolman pebble count was performed approximately 200 feet upstream of the existing culvert, between bankfull width measurements 1 and 2 (Figure 14). The grain size distribution is dominated by gravels and cobbles with a D_{50} of 1.01 inches, as summarized in Table 1. Figure 15 shows the distribution of sediment sizes at the location of the pebble count.

Figure 14 Streambed material photo upstream of SR 108 crossing

Table 1 Sediment properties downstream of SR 108 crossing

Particle	Diameter (in)
D_{15}	0.29
D_{35}	0.70
D_{50}	1.01
D_{84}	2.51
D_{95}	3.67
D_{100}	10.08

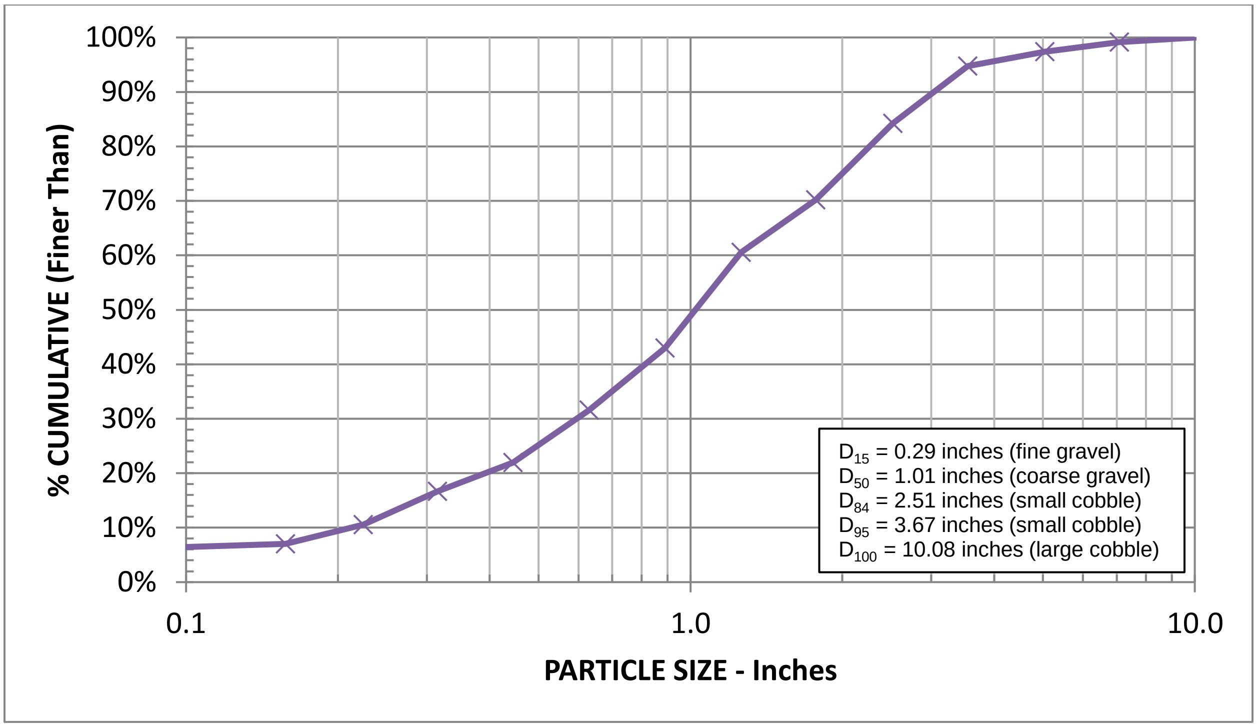


Figure 15 Wolman pebble count sediment size distribution

3.5 Groundwater

According to Washington State Department of Ecology (ECY) well logs and WDOE Environmental Information Management groundwater data, an in-stream piezometer (ID# ALP895) was installed in the Skookum Creek stream bed approximately 1000 feet east of the project site in 2004. The well was installed as part of Total Maximum Daily Load (TMDL) development efforts for segments of Skookum Creek. Stream depths and temperature were recorded but no groundwater level measurements were found for this well. The USGS National Water Information System groundwater monitoring database was also queried and no records were found for the site.

No obvious signs that groundwater might be close to the surface other than the flow in the channel were observed.

4.0 Fish Resources and Site Habitat Assessment

4.1 Fish Use

The portion of the Unnamed Tributary to Skookum Creek that is located within the project site supports the occurrence of fall-run coho salmon (*Oncorhynchus kisutch*), chum salmon (*Oncorhynchus keta*), winter-run steelhead (*Oncorhynchus mykiss*) and coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) (WDFW PHS data 2019a; WDFW Salmonscape 2019b; Streamnet 2019). Of these species, winter steelhead that inhabit the watershed are part of the Puget Sound Distinct Population Segment (DPS) and are federally listed as threatened under the Endangered Species Act (ESA) of 1973. Besides salmonids, several additional fish species, including sculpin and lamprey, also inhabit the watershed. Table 2 provides a list of native fish potentially found in Skookum Creek and its tributaries. The confluence of the Unnamed Tributary to Skookum Creek is within the study area just downstream (south) of the culvert crossing. There was very little water in the stream channel during the time of the site visit in August 2019, and no fish were observed.

Table 2 Native fish species potentially found

Species	Source (Assumed, Mapped, or Documented)	Pre-Existing Fish Use Surveys (spawner surveys or other biological observations)	Life History Present (Egg, Juvenile, Adult)	Limiting Habitat Factors	Stock Status and/or ESA Listing
Coho (*Onchorhynchus kisutch*)	Documented	Statewide Integrated Fish Distribution (SwIFD), Salmonscape, PHS	Juvenile, Adult	Spawning and Rearing	Not Warranted
Fall Chum (*Onchorhynchus keta*)	Documented	SwIFD, Salmonscape, PHS	Juvenile, Adult	Spawning and Rearing	Not Warranted
Winter Steelhead (*Onchoryhnchus mykiss*)	Documented	SwIFD, Salmonscape, PHS	Juvenile, Adult	Spawning and Rearing	Federally Threatened
Coastal Cutthroat (*Onchoryhnchus clarkii clarkii*)	Documented	SwIFD, Salmonscape, PHS	Egg, Juvenile, Adult	Spawning and Rearing	Not Warranted
Sculpin (*Cottus*)	Assumed	None	Egg, Juvenile, Adult	Spawning and Rearing	Not Warranted
Lamprey (Lampreta)	Assumed	None	Egg, Juvenile, Adult	Spawning and Rearing	Not Warranted

4.2 Existing Habitat

Skookum Creek is a significant watershed in South Puget Sound, with numerous tributaries providing habitat for salmonids. Land use at higher elevations is predominately timber production, with livestock and pasture/hayfields in the mid and lower valleys. The Skookum Creek watershed provides spawning and rearing habitat for coho, chum, steelhead, and cutthroat trout throughout the mainstem and accessible reaches of its tributaries. These anadromous species are part of Puget Sound stocks and access Skookum Creek through the Little Skookum Inlet off Totten Inlet in South Puget Sound.

In addition to fish passage barriers in the upper watershed, the most significant biological impairments are habitat diversity and quantity, sediment load and transport, and summer water temperatures. The Unnamed Tributary that crosses SR 108 at MP 5.5 is a left bank tributary to Skookum Creek that provides rearing and migratory habitat for salmonids and other fish species.

4.2.1 Immediate Crossing

The current crossing is undersized for the channel and classified as a barrier to fish passage due to its slope of more than 2%. It is considered to be a complete passage barrier, precluding upstream passage of both adult and juvenile salmonids. The current conditions therefore prevent use of the tributary reaches upstream of the crossing by migratory coho, chum, steelhead, and cutthroat trout, and disrupt sediment and debris transport downstream.

4.2.2 Quality Within Reach

Downstream of the SR 108 culvert crossing, the Unnamed Tributary flows through mixed canopy of mostly deciduous trees containing alder (*Alnus rubra*) and big leaf maple (*Acer macrophyllum*), with some conifers including Douglas fir (*Pseudotsuga menziesii*) and western red cedars (*Thuja plicata*). There is a dense shrub understory with native and non-native species including salmonberry (*Rubus spectabilis*), vine maple (*Acer circinatum*), and Himalayan blackberry (*Rubus armeniacus*). The mature forest and shrub cover provides good shading, nutrient inputs, and some potential large woody material (LWM) recruitment. There were four pieces of LWM observed in the downstream reach, and a small cascade where the channel narrows at the downstream end of the study reach.

At the culvert outlet there is a small scour pool that joins with the confluence of Skookum Creek. The downstream stream channel contains riffles and shallow pools within the project reach. The streambed substrate is comprised of fines, small gravels, and cobbles. Mid-channel sediment bars have formed throughout the reach. Habitat in this reach is predominantly suited to seasonal migration and rearing, particularly during higher flow periods. There is some potential spawning habitat, and some shallow pool-riffle complexes that provide some in-stream habitat complexity.

The confluence with Skookum Creek is located within a few feet of the culvert outlet. Skookum Creek continues for approximately 7.7 miles to where it enters Little Skookum Inlet, and on to Totten Inlet off Puget Sound.

Upstream of the SR 108 crossing, the Unnamed Tributary flows through a mature mixed forested area comprised primarily of fir, alder, and big leaf maple, with some large cedars. There is a dense shrub understory with native and non-native species including salmonberry, willows (*Salix spp.*), vine maple, and Himalayan blackberry. The mature forest and shrub cover provides good shading, nutrient inputs, and high potential LWM recruitment. There were three areas upstream of the crossing where some short pieces of LWM and smaller branches were in the bed and banks.

The culvert inlet is located at the base of a high, steep road embankment covered in grasses and shrubs, with a thick cover of Himalayan blackberry at the base. The stream channel is predominantly riffle habitat with gravel and some cobble in the substrate, with some mid-channel sediment bars present throughout. Pool habitat is lacking in the upstream reach. The channel narrows at the culvert inlet but widens upstream, and is slightly incised with banks of about 1.5 to 2.5 feet high. Habitat in this reach is predominantly suited to seasonal migration and some rearing, particularly during higher flow periods. There is limited potential spawning habitat, and pool-riffle complexes are lacking, but small amounts of LWM provide some in-stream habitat complexity.

4.2.3 Length of Potential Gain

In October of 2007, WDFW surveyed 1.75 miles (9,232 feet) of the Unnamed Tributary upstream of the project site. There are two culvert crossings upstream that have been restored to passable condition. The upstream reach was documented as providing 0.4 acres of potential spawning habitat, and 0.9 acres of potential rearing habitat (WDFW report 991237).

4.2.4 Other Barriers in System

Currently there is a single passage barrier at a culvert located upstream of the project reach of the Unnamed Tributary, and another barrier located on a small right bank tributary to the Unnamed Tributary. The closest barrier is a culvert at approximately 1,184 feet upstream of the project crossing (Site ID 115 MC263). There are two culvert crossings on the Unnamed Tributary further upstream that have been replaced with fish passable culverts. WDFW also reported an abandoned road and removed culvert further upstream, but this remains a barrier as it was not replaced with a fish passable culvert (WDFW report 991237).

Downstream of the crossing under SR 108 the Unnamed Tributary enters Skookum Creek, which flows roughly eastward and crosses under SR 108 twice and US 101 before entering the Little Skookum Inlet. These crossings are bridges; there are no fish passage barriers in Skookum Creek downstream of the project crossing.

Figure 16 presents a map of Skookum Creek, the Unnamed Tributary, and the fish passage features that were documented by WDFW during their fish passage inventory and habitat surveys.

4.2.5 Other Restoration Efforts in System

A culvert crossing on West Cloquallum Truck Trail forest road was replaced with a larger fish passable culvert in 2005 (Site ID 115 MC081). Other restoration efforts in the area involve the Skookum Creek watershed. Commercial timberlands dominate the headwaters and upper watershed, while agricultural pasturelands, rural residential and urban development make up the majority of the valley floor through the lowlands.

The Squaxin Island Tribe owns portions of land in the lower reaches of Skookum Creek and its tributaries as it runs through the reservation. The Tribe, along with conservation groups, have several completed and ongoing restoration and preservation projects in the Skookum Creek watershed. Tribal restoration projects in the watershed have improved freshwater habitat for salmonids, particularly for the coho run. Where Skookum Creek runs through Tribal property, the Squaxin Island Tribe has set aside 150-foot buffers on each side of the creek to protect ecological functions, and has begun replanting efforts.

The Tribe has also worked with the South Puget Sound Salmon Enhancement Group to dig out the steep, eroded banks of the lower creek. Instead of the near vertical 10-foot wall that previously existed, the streambank is now at a gentle slope and creates floodplain connectivity. Additionally, the partners are building logjams to recreate natural conditions of in-stream habitat to help create pools where adult salmon can rest while migrating upstream and rearing juveniles can find refuge.

Work has been undertaken to place additional wood in the tributaries, with substantial LWD and key pieces being added to Reitdorf Creek, in 2002 with the use of helicopters. McDonald Creek is the focus of two Family Forest Fish Passage Program projects, each removing previous partial barriers upstream of the SR 108 crossing.

The Washington Wildlife and Recreation Coalition is working in partnership with the Squaxin Island Tribe to help acquire and permanently protect 158 acres of wetlands and shorelines along Skookum Creek, using grant funding for the Skookum Valley Wetland Acquisition. The Squaxin Island Tribe’s plans to buy up to 614 acres in the Skookum Valley, depending on landowners’ willingness. This project will protect more than 4 miles of Skookum Creek and an additional 4.4 miles of tributaries, as well as a number of wetlands, stream banks, and forests.

Though there have been restoration efforts on Skookum Creek and other tributaries, there are no known completed or planned future restoration efforts on this tributary.

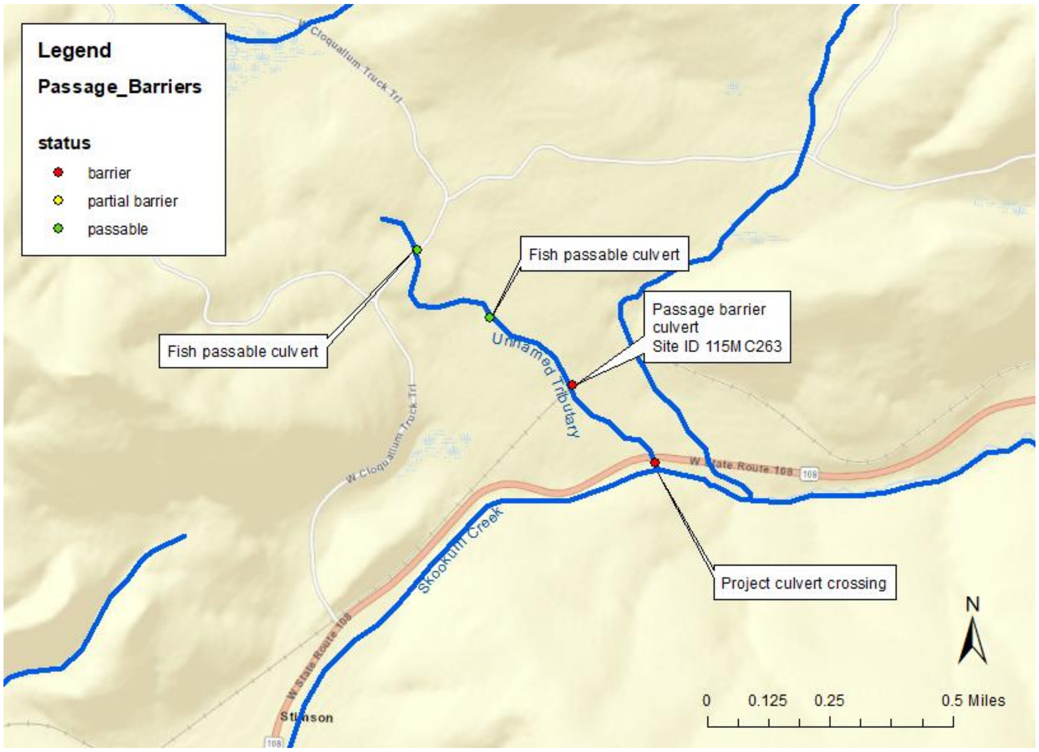


Figure 16 Fish passage features located on the unnamed tributary to Skookum Creek

5.0 Reference Reach Selection

A reference reach was selected upstream of the existing culvert between two bankfull widths approximately 150 to 250 feet upstream of the existing culvert inlet. A reference reach was not selected downstream of the crossing because a tributary joins the stream just downstream of the culvert outlet, and the downstream channel geometry would not be representative of the channel width at the culvert.

Two bankfull width measurements were taken approximately 150 feet and 250 feet upstream of the existing culvert inlet, which measured 11 feet and 10.8 feet, respectively. For comparison, a bankfull width was calculated based on the WDFW regression equation for high-gradient, coarse-bedded streams in western Washington, using the basin area (0.34 square miles) and average mean annual precipitation (91.2 inches/year). The calculated bankfull width of 9.2 feet is 16-17% smaller than the bankfull widths measured in the field. Bankfull widths were not taken downstream of the crossing for the same reason a reference reach was not selected there. During the stakeholder site visit with WDFW, it was agreed upon to average the two bankfull widths for a design bankfull width of 10.9 feet.

A pebble count was performed approximately 200 feet upstream of the existing SR 108 culvert, between bankfull width measurements 1 and 2. The result of the pebble count is discussed in Section 3.4.6. Figure 17 shows the approximate BFW measurement and pebble count locations.

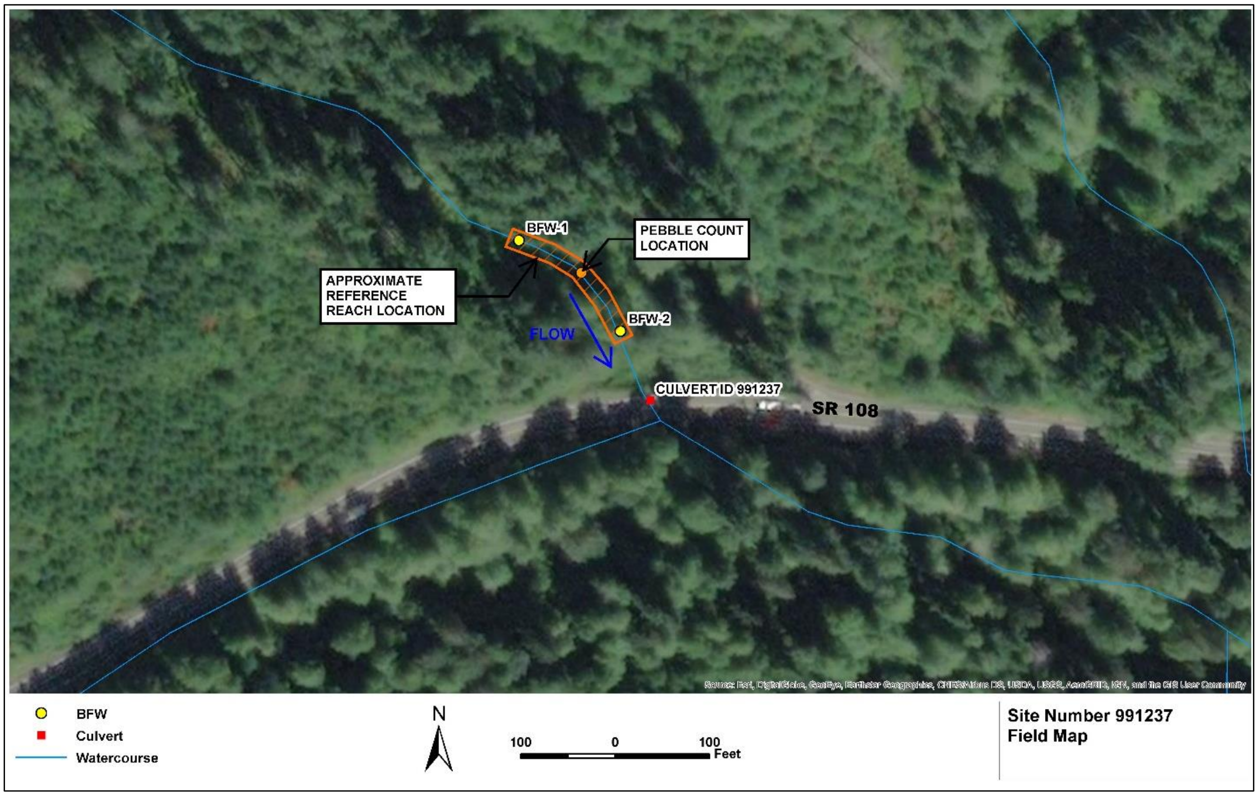


Figure 17 Bankfull width and pebble count measurement locations

6.0 Hydrology and Peak Flow Estimates

Peak flow estimates for the Unnamed Tributary to Skookum Creek were obtained from the USGS Regression Equation (Mastin, et al., 2016). The Unnamed Tributary to Skookum Creek has a basin area of 0.34 square miles and a mean annual precipitation within the basin of 91.2 inches (Prism, 2019). The Unnamed Tributary flows into Skookum Creek directly downstream of the culvert. Skookum Creek has a basin area of 0.40 square miles and a mean annual precipitation within the basin of 90.5 inches (Prism, 2019). Table 3 and Table 4 show the calculated peak flows and prediction intervals (at a 90% confidence level) for the Unnamed Tributary to Skookum Creek at SR 108 and Skookum Creek upstream of the confluence.

Table 3 Peak flows, Standard Error of Prediction and Prediction Intervals (at a 90% confidence interval) for the Unnamed Tributary to Skookum Creek at SR 108

Mean Recurrence Interval (MRI)	Unnamed Tributary at SR 108 (cfs)	Standard Error of Prediction	Prediction Interval (lower)	Prediction Interval (upper)
2	30.0	43.2	15.0	59.9
5	46.2	44.4	22.6	94.3
10	56.7	45.6	27.4	117
25	69.7	48.1	32.3	150
50	79.0	50.5	35.5	176
100	89.1	51.8	39.3	202
200	98.7	54.2	41.9	232
500	112	57.7	45.5	276

Table 4 Peak flows, Standard Error of Prediction and Prediction Intervals (at a 90% confidence interval) for Skookum Creek

Mean Recurrence Interval (MRI)	Skookum Creek (cfs)	Standard Error of Prediction	Prediction Interval (lower)	Prediction Interval (upper)
2	34.3	43.2	17.2	68.4
5	52.7	44.4	25.8	108
10	64.8	45.6	31.4	134
25	79.7	48.1	37.0	172
50	90.3	50.5	40.7	200
100	102	51.8	45.1	231
200	113	54.2	48.1	266
500	128	57.7	52.1	315

7.0 Hydraulic Analysis

The hydraulic analysis of the existing and proposed Unnamed Tributary crossing was performed using Bureau of Reclamation’s SRH-2D Version 3.2.0 (USBR, 2017) computer program, a two-dimensional hydraulic and sediment transport model. It includes the ability to model dynamic interactions between the stream channel and overbanks, roadway overtopping, culverts, and the influence of bridge decks on bridge backwater. Pre- and post-processing of the model was completed using SMS Version 13.0.5 (Aquaveo, 2018). Appendix A contains detailed output from the hydraulic modeling effort.

Two scenarios were analyzed for determining stream characteristics for the Unnamed Tributary to Skookum Creek with the SRH-2D models: 1) existing conditions with the 36-inch diameter concrete culvert and 2) future conditions with the proposed 16 foot hydraulic opening.

7.1 Model Development

7.1.1 Topography

Detailed channel geometry data in the model was obtained from the MicroStation and InRoads files, which were developed from topographic surveys performed by Lin & Associate surveyors. Proposed channel geometry was developed from the proposed grading surface created by HDR Engineering, Inc.

7.1.2 Model Extent and Computational Mesh

The hydraulic model upstream and downstream extents are consistent with the detailed survey boundary, approximately 280 feet upstream of the existing culvert outlet and 310 feet downstream of the existing culvert outlet, measure along the channel centerline. The computational mesh elements was a combination of patched and paved (triangular) elements, with finer resolution in the channel and larger elements in the floodplain (Figure 18).

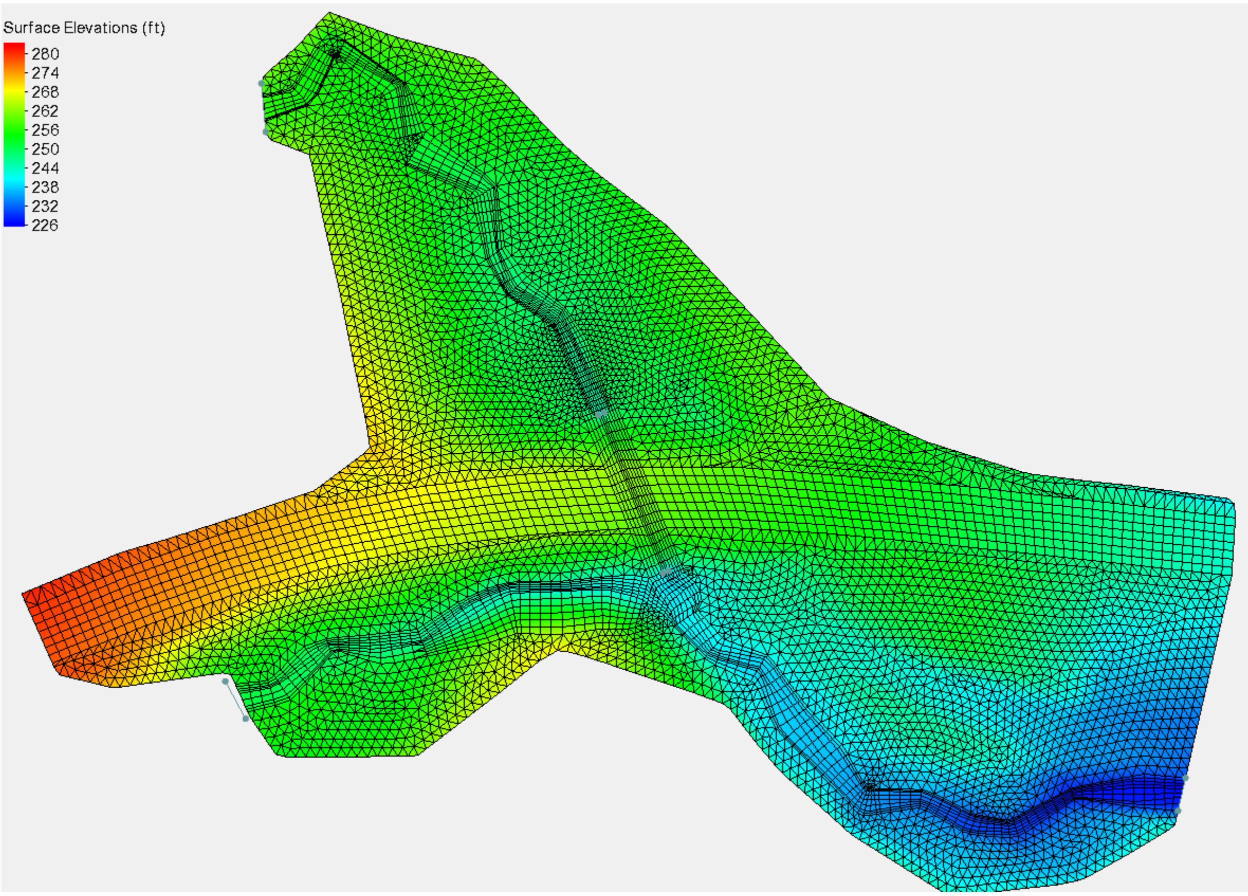


Figure 18 Existing computational mesh with underlying terrain

7.1.3 Roughness

Manning's n values were estimated based of site observations, aerial photography and standard engineering values (Chow, 1959) and are summarized below (Table 5). Roughness in the overbanks represents dense vegetation and undergrowth associated with the grasses, shrubs and trees in the riparian areas.

Table 5 Summary of roughness coefficients

Land Cover	Manning's Roughness Coefficient
Road	0.02
Dense Vegetation and Undergrowth	0.1
Road Embankment	0.05
Gravel	0.025
Channel	0.045

7.1.4 Boundary Conditions

Model simulations were performed using multiple quasi-steady state discharges ranging from the 2-year to 500-year peak flow events summarized described in Chapter 6. External boundary conditions were applied at the upstream and downstream extents of the model and remained the same between the existing and proposed conditions runs. A constant flow rate was specified at the upstream external boundary condition, while a normal depth rating curve was specified at the downstream boundary. The downstream normal depth boundary condition rating curve was developed within SMS using the existing terrain, assuming a downstream slope of 4% as measured from the survey and a composite roughness of 0.05.

A HY-8 internal boundary condition was specified in the existing conditions model to represent the existing circular concrete culvert crossing. The existing crossing was modeled as a 3 foot diameter circular pipe within HY-8. A manning's roughness of 0.012 was assigned to the culvert. The culvert was assumed to be unobstructed and free from any stream material within the barrel.

7.1.5 Model Geometries

Two geometries were developed for simulation with SRH-2D, representing existing and proposed conditions. The existing conditions includes the existing circular concrete culvert crossing of SR 108. The existing condition geometry was modified to develop the proposed conditions by removing the existing culvert and associated internal boundary conditions. Additionally the terrain was updated to reflect the proposed grading and 16-foot span hydraulic opening. The walls of the proposed structure were modeled as voids in the computational mesh.

7.2 Model Results

Hydraulic results were summarized and compared at common locations between the existing and proposed simulations (Figure 19). The upstream cross section is located at approximate station 4+97 and is 30 feet upstream of the existing culvert inlet. Downstream the cross section was located at station 2+21, 100 feet downstream of the existing culvert outlet on the mainstem of Skookum Creek. Channel hydraulic variables reported include water surface elevation, depth, velocity and shear stress. Appendix A contains the more detailed hydraulic output.

In addition to cross section results, results were summarized along the longitudinal profile. Both existing and proposed conditions use the same alignment (Figure 20).

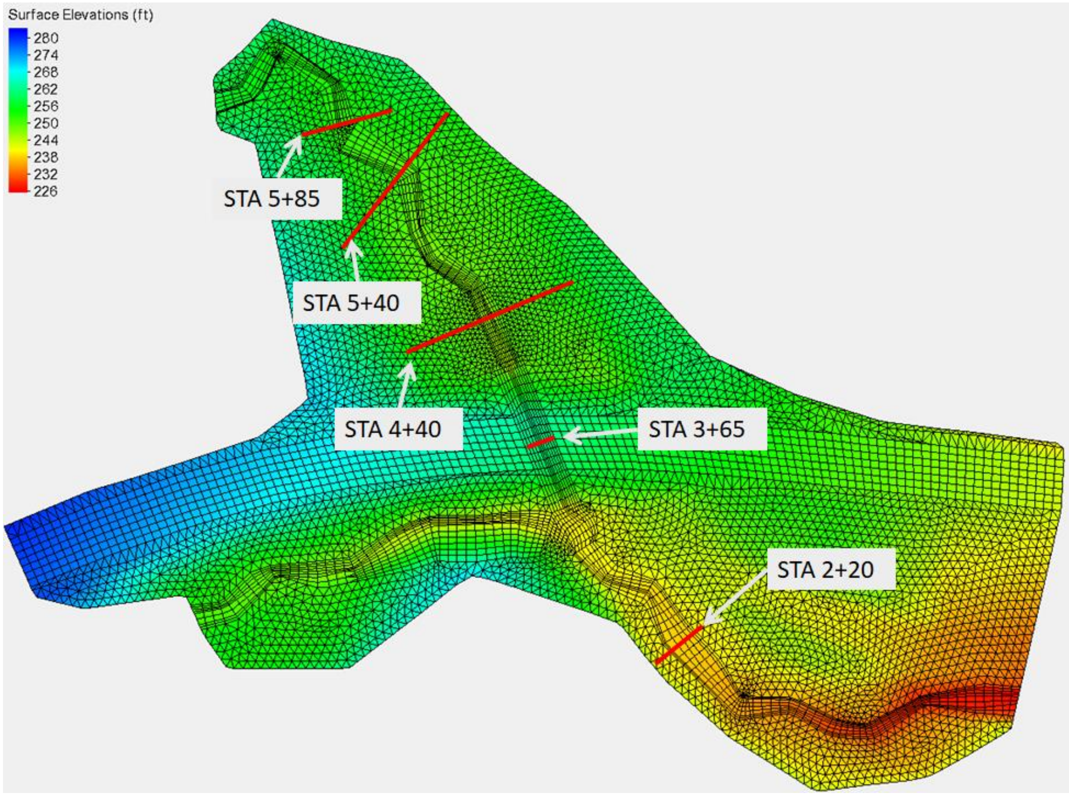


Figure 19 Locations of cross sections used for results reporting

Figure 20 Longitudinal profile stationing for reporting existing and proposed model results

7.2.1 Existing conditions – 3 foot circular, concrete culvert

Existing conditions hydraulic results are summarized for the upstream and downstream cross sections in Table 6 below. Under existing conditions, the culvert causes a backwater upstream for the range of flows simulated (Figure 21). Pressure flow conditions are first observed during the 25-year event simulation, where water surface elevations as high as 249.0 ft reach above the top of the culvert opening (246.9 ft). The 2-year event water surface (246.3 ft) does not submerge the culvert inlet, so pressure flow conditions are not yet observed at this flow. The existing roadway was not overtopped by the 500-year event.

As a result of the backwater, the upstream depths are greater than the downstream reach. In addition, the upstream shear and velocities are lower than their downstream counter parts. Upstream channel velocities varied from 5.86 ft/sec during the 2-year event to 0.47 ft/sec during the 500-year event. At the downstream cross section velocities ranged from 4.45 ft/sec at the 2-year event to 7.63 ft/sec at the 500-year event. Shear varied from 2.27 lb/ft^2 to 0.01 lb/sq ft at the upstream cross sections during the 2-year and 500-year events, respectively. Larger shear values were present in the downstream cross section, ranging from 1.33 lb/ft^2 during the 2-year event to 2.82 lb/ft^2 at the 500-year event. When looking at the entire model domain, the largest velocities occurred at the culvert outlet and at steeper, confined areas in the mainstem Skookum Creek reach about 200 feet downstream of the culvert (Figure 22).

Table 6 Hydraulic results for existing conditions within channel

Hydraulic Parameter	Cross Section	2-yr	25-yr	50-yr	100-yr	500-yr
Average Water Surface Elevation (ft)	XS 5+85	252.25	252.60	252.68	252.81	253.83
	XS 5+40	250.18	250.63	250.72	251.09	253.90
	XS 4+40	246.57	248.98	249.90	251.01	253.91
	XS 2+20	238.12	238.70	238.81	238.92	239.15
Max Depth (ft)	XS 5+85	0.78	1.15	1.22	1.30	2.36
	XS 5+40	0.92	1.45	1.55	1.87	4.53
	XS 4+40	1.14	3.55	4.47	5.58	8.48
	XS 2+20	1.00	1.62	1.74	1.86	2.11
Average Velocity (ft/s)	XS 5+85	3.72	5.45	4.98	5.86	3.90
	XS 5+40	3.90	5.09	5.33	4.88	1.53
	XS 4+40	3.79	2.13	1.68	1.04	0.47
	XS 2+20	4.45	6.38	6.70	7.02	7.63
Average Shear (lb/sq-ft)	XS 5+85	1.16	2.20	2.18	2.27	0.83
	XS 5+40	1.31	2.01	2.13	1.53	0.10
	XS 4+40	1.06	0.19	0.11	0.04	0.01
	XS 2+20	1.33	2.20	2.34	2.51	2.82

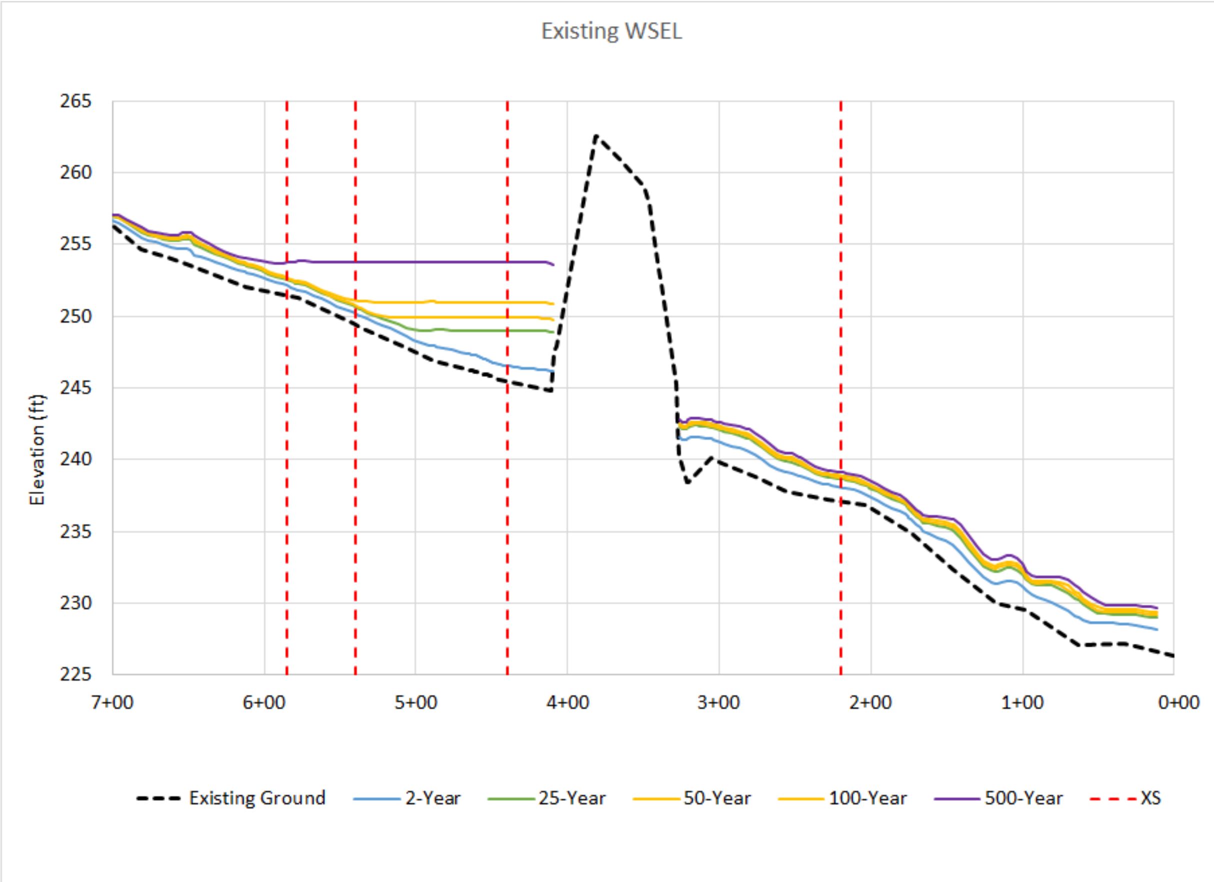


Figure 21 Existing conditions water surface profiles

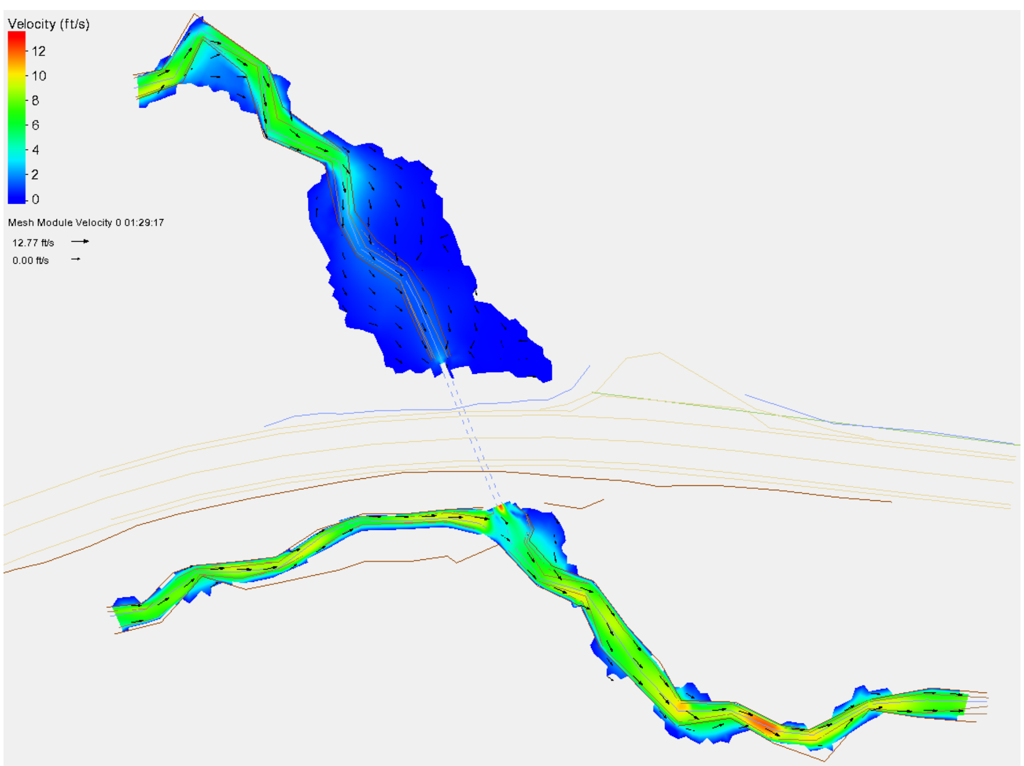


Figure 22 Existing conditions 100-year velocity map

7.2.2 Future conditions – Proposed 16 Foot Span Structure

Proposed conditions hydraulic results are summarized in Table 7. The larger proposed structure reduced water surface elevations upstream and did not result in any backwater (Figure 23). The 100-year water surface elevation upstream of the crossing was decreased by 4.29 feet when compared to existing conditions.

With the removal of the backwater condition, upstream channel velocities increased from existing conditions, varying from 3.54 ft/sec during the 2-year event to 6.62 ft/sec during the 500-year event. Downstream, velocities matched existing conditions within 0.01 ft/sec, varying from 4.44 to 7.64 ft/sec. Similar to the velocity results, shear increased upstream of the crossing, varying from 1.14 to 2.82 lb/ft^2. At the downstream cross section, shear values matched existing conditions. The hydraulics under the proposed crossing indicate this reach is a transition from the reach upstream of the crossing to the downstream reach. Velocities, depths, and shear within the proposed crossing are all between the results of the upstream and downstream cross section. When looking at the entire model domain, proposed velocities upstream of the crossing increased compared to existing conditions. The velocity at the outlet of the crossing into the existing scour hole is anticipated to decrease (Figure 24).

Table 7 Hydraulic results for proposed conditions within channel

Hydraulic Parameter	Cross Section	2-yr	25-yr	50-yr	100-yr	500-yr
Average Water Surface Elevation (ft)	XS 5+85	252.25	252.60	252.68	252.81	252.97
	XS 5+40	250.21	250.65	250.75	250.85	250.99
	XS 4+40	246.11	246.54	246.62	246.72	246.94
	XS 3+65	242.80	243.23	243.31	243.39	243.57
	XS 2+20	238.11	238.70	238.81	238.93	239.16
Max Depth (ft)	XS 5+85	0.78	1.14	1.22	1.30	1.47
	XS 5+40	0.96	1.49	1.58	1.68	1.86
	XS 4+40	1.01	1.43	1.51	1.62	1.84
	XS 3+65	1.00	1.43	1.51	1.59	1.76
	XS 2+20	1.00	1.62	1.74	1.86	2.12
Average Velocity (ft/s)	XS 5+85	3.71	5.46	4.99	5.86	6.35
	XS 5+40	3.89	5.36	5.61	5.95	6.62
	XS 4+40	3.54	5.11	5.44	5.84	6.62
	XS 3+65	3.56	5.20	5.46	5.80	6.65
	XS 2+20	4.44	6.38	6.69	7.01	7.64
Average Shear (lb/sq-ft))	XS 5+85	1.14	2.20	2.17	2.27	2.56
	XS 5+40	1.32	2.10	2.18	2.27	2.60
	XS 4+40	1.31	2.39	2.60	2.69	2.82
	XS 3+65	1.31	2.43	2.63	2.84	3.28
	XS 2+20	1.33	2.20	2.35	2.51	2.83

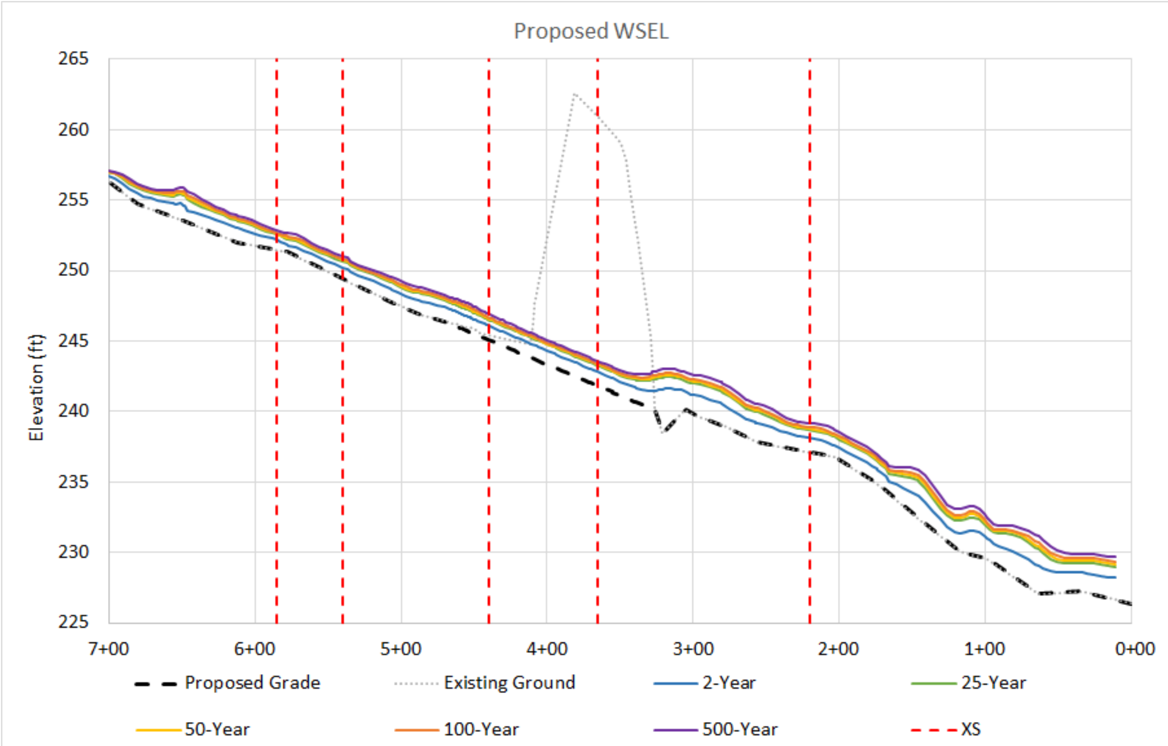


Figure 23 Proposed conditions water surface profiles

Figure 24 Proposed conditions 100-year velocity map

8.0 Fish Passage Design Methods Selection

8.1 Design Methodology Selection

The WCDG contains methodology for five different types of crossings: No-Slope Culverts, Stream Simulation Culverts, Bridges, Temporary Culverts or Bridges, and Hydraulic Design Fishways. The permanent federal injunction allows for the use of the stream simulation method and bridge design method unless extraordinary circumstances exist on site. According to the WCDG, a bridge should be considered for a site if the Floodplain Utilization Ratio (FUR) is greater than 3.0, the stream has a bankfull width of greater than 15 feet, the channel is believed to be unstable, the slope ratio exceeds 1.25 between the existing channel and the new channel, or the culvert would be very long. Using these design criteria, stream simulation design was deemed the most appropriate method for this crossing because the bankfull width is less than 15 feet and the channel is confined.

8.2 Stream Simulation Criteria

One of the criteria for using the stream simulation is the Floodplain Utilization Ratio (FUR). The FUR is defined as the flood-prone width (FPW) divided by the bankfull width. The FPW is the water surface width at twice the bankfull depth, or the width at the 50-year to 100-year flood. A ratio under 3.0 is considered a confined channel and above 3.0 is considered an unconfined channel. Crossings using the stream simulation design methodology should be confined with a FUR of less than or equal to 3.0. The entire project reach of the Unnamed Tributary to Skookum Creek, when removing the culvert backwater influence, has a FUR of less than 3.0 and is considered a confined channel. The FUR upstream of the culvert inlet typically varies between 2.3 and 1.4. There is one location approximately 100 feet upstream of the culvert where the left bank floodplain is lower and the floodplain is wider than in all other locations, in this location the FUR is 3.4.

8.2.1 Culvert Span and Length

The WCDG recommends sizing the span of the proposed structure based on the agreed upon bankfull width, with the span being 1.2 x bankfull width + 2 feet (WCDG Equation 3.2). Using this equation, along with the measured bankfull width of 10.9 feet discussed in Section 5.0, results in a structure span of 15.1 feet. Rounding up to the nearest whole foot results in a recommended structure span of 16 feet. The proposed culvert is approximately 70 feet in length, assuming the road embankment slopes are not impacted. Effort should be made during later design phases to reduce the total length of the culvert to the extent practicable.

8.2.2 Backwater and Freeboard

The WCDG recommends the prevention of excessive backwater rise and increased main channel velocities during floods that might lead to scour of the streambed and coarsening of the stream substrate, allow the free passage of debris expected to be encountered, and generally suggests a minimum 2 foot freeboard for streams of this size. It is practicable to meet the minimum 2 feet of freeboard at this crossing, because the road embankment height is approximately 19 feet.

An additional consideration is that a minimum of 5 feet above the thalweg should be provided if practicable to perform future maintenance, allowing for wildlife to cross, and performing monitoring activities. The proposed 100-year depth at the crossing 1.59 feet, adding 2 feet of freeboard does not meet the minimum recommended 5 foot of clearance. Therefore, the recommended structure should have 5 feet of clearance from the thalweg and assuming 3 feet of countersink the culvert rise would be 8 feet.

8.2.3 Channel Planform and Shape

The WCDG requires that the channel planform and shape mimic conditions within a reference reach. The proposed channel shape includes 10H:1V slopes between the toes and 2H:1V banks slopes to create a channel similar to the observed existing channel shape (Figure 25).

Channel habitat features will be implemented to create channel complexity. See Section 9.4 for further descriptions of the channel habitat features.

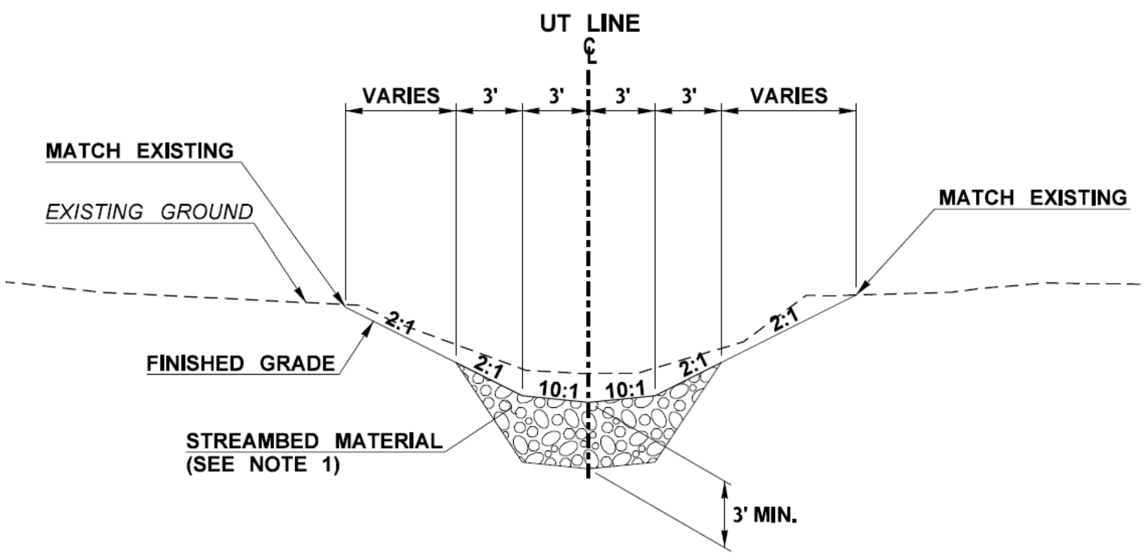


Figure 25 Typical channel section

8.2.4 Floodplain Continuity and Lateral Migration through Structure

The WCDG requires that bridges account for lateral channel movement that will occur in their design life and that the design channel maintains floodplain continuity. The existing channel upstream only showed one location of lateral migration approximately 150 feet upstream. This migration appears to be driven by LWM that had fallen into the channel causing bank erosion. The channel within 100 feet upstream of the culvert show limited ability to migrate laterally.

8.2.5 Channel Gradient

The WCDG recommends that the proposed culvert bed gradient not be more than 25% steeper than the existing stream gradient upstream of the crossing (WCDG Equation 3.1). The proposed channel gradient is 4.37% and the slope upstream of the project is approximately 4%, resulting in a slope ratio of 1.1.

9.0 Streambed Design

9.1 Alignment

The proposed project alignment follows the existing alignment. The project will consist of channel grading approximately 70 feet upstream of the crossing. The downstream finished grade will tie into the existing grade just downstream of the culvert and upstream of the confluence with Skookum Creek. The alignment and grading extents are illustrated in design drawings provided in Appendix B.

9.2 Proposed Section

Description of the existing and proposed cross section are presented in Section 8.2.3. A low flow channel will be added in later stages of the project that connect habitat features together and ensure the project is not a low flow barrier. The low flow channel will be as directed by the Engineer in the field.

9.3 Bed Material

The proposed bed material gradation was created using standard WSDOT specification material to mimic the gradation documented in the pebble count as best as possible. The proposed mix will consist of 50% Streambed Sediment and 50% 4” Streambed Cobbles. This is most representative of the native streambed material observed during the site visit. A comparison of the observed and proposed streambed material distribution is provided in Table 8. Mobility will be assessed during the FHD phase and a determination of the necessity of changing the proposed material size will be made then.

Table 8 Comparison of observed and proposed streambed material

Particle	Observed Material Diameter (in)	Proposed Material Diameter (in)
D_{15}	0.29	0.6
D_{50}	1.01	1.3
D_{84}	2.51	2.6
D_{95}	3.67	3.5
D_{100}	10.1	4.0

Coarse bands are incorporated into the design. Coarse bands were spaced at approximately 20 feet on center and alternate sides of the culvert to promote sinuosity. The proposed coarse band material is 50% Streambed Sediment and 50% 10” Streambed Cobbles

9.4 Channel Habitat Features

Large Woody Material will be installed in portions of Unnamed Tributary to Skookum Creek. These LWM installations will provide structures conducive to create stream complexity and geomorphic functions in segments that will have low natural LWM delivery rates while new and impacted riparian areas recover from construction activities related to the installation of the new crossing and the regrading of the stream channels. LWM, in conjunction with habitat boulders and bank-side bioengineering, will also help protect newly constructed banks and will promote long-term bed stability by creating pools, sinuosity, hard points, and channel roughness.

9.4.1 Design Concept

The 75th percentile of key piece density per Fox and Bolton (2007) and Chapter 10 of the Hydraulics Manual recommend 3.3 key pieces per 100 feet of channel. This percentile of wood placement is suggested to compensate for cumulative deficits of wood loading due to development. A conceptual LWM layout has been developed for the Unnamed Tributary project area and is provided in Figure 26. The conceptual layout proposes 6 key pieces. The project reach is 145 feet long (including the structure length), yielding 4.1 key pieces per 100 feet of linear channel, 24% more than the Fox and Bolton (2007) 75th percentile criteria to account for portions of the channel where infrastructure limits LWM placement.

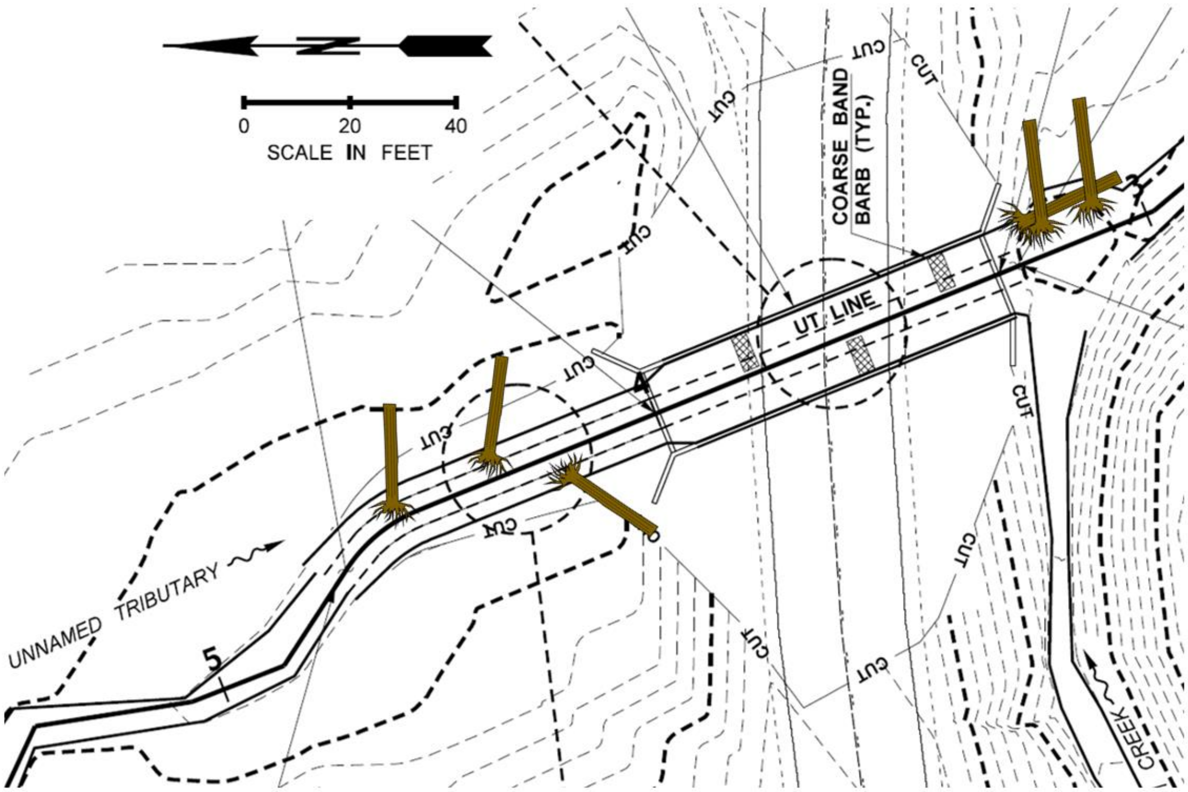


Figure 26 Proposed grading and conceptual wood layout

10.0 Floodplain Changes

This project is within a FEMA Zone A mapped floodplain. The FEMA Zone A mapped floodplain is for Skookum Creek and is on the downstream end of the SR108 crossing. A detailed model and study has not been created for the Unnamed Tributary to Skookum Creek. The pre-project and expected post-project conditions were evaluated to determine whether or not there would be a change in water surface elevation and floodplain storage.

10.1 Floodplain Storage

Floodplain storage is anticipated to be nearly unaffected and may increase slightly due to the removal of the undersized culvert and replacement with a larger hydraulic opening. The installation of a larger hydraulic opening reduces the amount of backwater being stored upstream of the crossing and reduces any peak flow attenuation that was being provided by the smaller, existing culvert. Changes to peak flow reduction was not quantified as the models were run in a quasi-steady state flow with a constant flow rate specified at the upstream boundary of the model.

10.2 Water Surface Elevations

Installation of the proposed structure would eliminate the backwater impacts upstream of the existing culvert, resulting in a reduction in water surface elevation. Preliminary hydraulic results indicate that there is a reduction in water surface elevation of 4.29 and 6.97 feet during the 100 and 500-year events at the upstream cross section, respectively. With the exception of small area in the downstream existing scour hole, the downstream water surface elevations matched between existing and proposed conditions. Figure 27 provides a comparison of the existing and proposed 100-year water surface profile. The hydraulic simulations indicate a localized increase in water surface elevations at the outlet of the proposed crossing (Figure 27) with a maximum increase of approximately 0.7 feet (Figure 28). In the existing conditions model this area is where the internal boundary conditions for the culvert is located and the mesh elevation was lowered below the culvert inverts. The difference is water surface can be likely attributed to the model limitations in computing hydraulic results at this area, where the exiting culvert is perched and flow is plunging as it enters the scour pool high at high velocities.

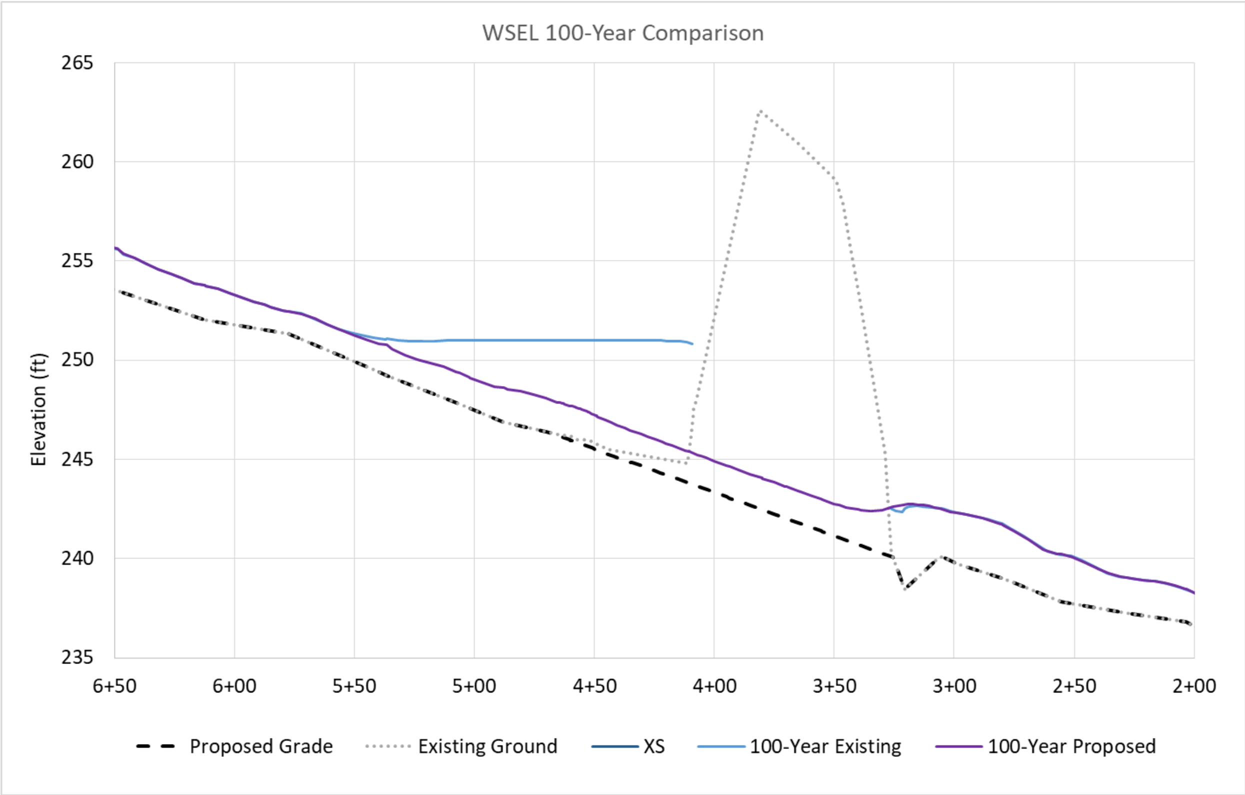


Figure 27 Existing and proposed 100-Year water surface profile comparison

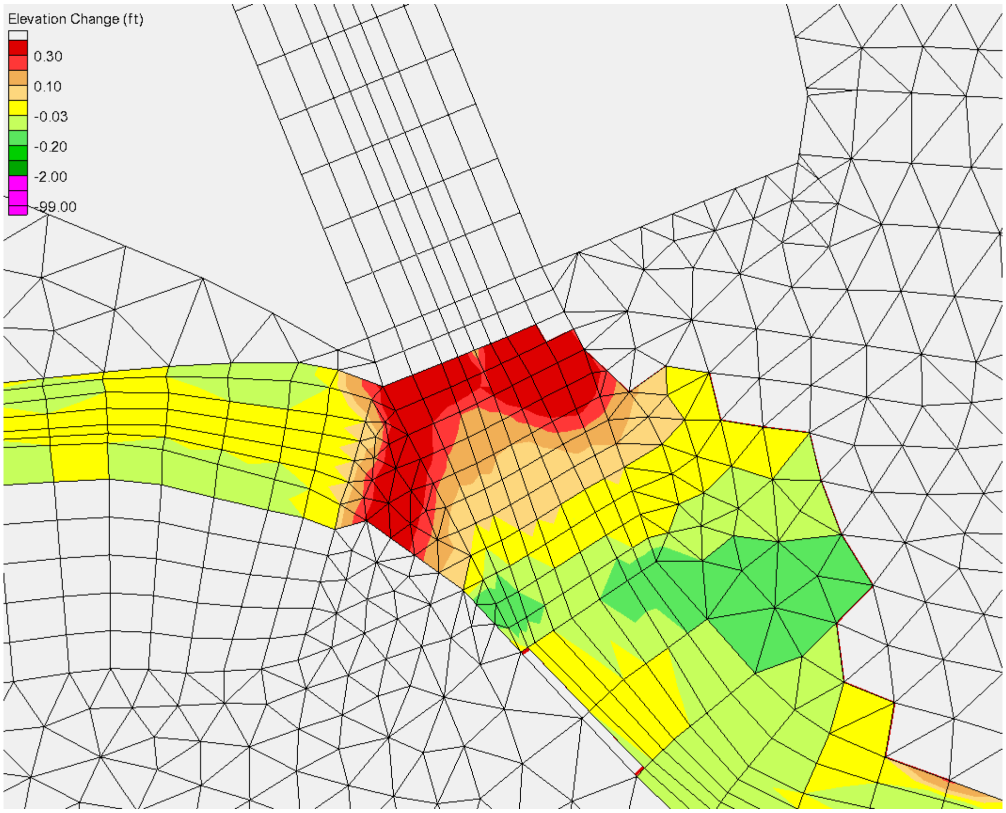


Figure 28 Change from existing conditions water surface elevation

11.0 Climate Resilience

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges, and buried structures through a risk based assessment beyond the design criteria. For bridges and buried structures, the largest risk to the structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and maintain passability for all expected life stages and species in a system.

11.1 Climate Resilience Tools

Climate resilience is evaluated at each crossing using the Climate Impacts Vulnerability Assessment Maps created by WSDOT to assess risk level of infrastructure across the state. The SR 108 crossing at the Unnamed Tributary to Skookum Creek has been evaluated and determined to be a low risk site based on the Climate Impacts Vulnerability Assessment Maps.

WSDOT also evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. For low or medium risk sites, the 2040 percent increase is used. For high risk sites the 2080 percent increase is used. Appendix E contains the information received from WDFW for this site. The 100-year flow event was chosen to be evaluated, because, as it is an extreme event, if the channel behaves similarly through the structure during this event as it does the adjacent reaches, then it is anticipated this relationship would also be true at lower flows as well.

11.2 Hydrology

For each design WSDOT uses, the best available science for assessing site hydrology. The predicted flows are analyzed in the hydraulic model and compared to field and survey indicators, maintenance history, and any other available information. Hydraulic engineering judgment is used to compare model results to system characteristics; if there is significant variation, then the hydrology is re-evaluated to determine whether or not adjustments need to be made, including adding standard error to the regression equation, basin changes in size or use, etc.

In addition to using the best available science for current site hydrology, WSDOT is evaluating the structure at the 2040 projected 100-year flow event to check for climate resiliency. The Design Flow for the crossing 89.1 cfs at the 100-year storm event. The projected increase for the 2040 flow rate is 3.7%, yielding a projected 2040 flow rate of 92.4 cfs.

11.3 Structure Width

The minimum width for a crossing given by Equation 3.2 was 15.1 feet. Structures come in whole foot increments for width, as a result, the width was increased to 16 feet to accommodate constructability and manufacturability. This structure width was evaluated at the 100-year flow event and projected

2040 100-year flow event and determined to produce similar velocities through the structure and adjacent reaches. The velocity comparisons for these flow rates can be seen in Table 9 below.

Table 9 Velocity Comparison for 16 Foot structure

	100-Year Velocity (ft/s)	Projected 100-Year Velocity (ft/s)	Difference (ft/s)	Difference (%)
Upstream of Structure (XS 4+40)	5.84	6.09	0.25	4.28
Through Structure (XS 3+65)	5.80	5.94	0.14	2.41
Downstream of Structure (XS 2+20)	7.01	7.05	0.04	0.057
Velocity Ratio	0.99	1.02	-	-

Note: Velocity ratio calculated as Vstructure/Vupstream

11.4 Freeboard and Countersink

The minimum recommended freeboard at this location based on bankfull width is 2 feet at the 100-year flow event. As discussed in Section 8.2.2, the structure height was increased to meet the minimum clearance to 5 feet from the thalweg. The proposed design has a depth of 1.59 feet at the 100-year flood event and 1.62 feet at the 2040 projected 100 year flow event. Assuming an 8-foot culvert rise and countersink of 3 feet, the freeboard is 3.41 feet at the 100-year flood event and 3.38 feet at the 2040 projected 100 year flow event, exceeding the minimum freeboard requirement.

Long term degradation and aggregation, contraction scour and local scour were not evaluated for this preliminary hydraulic design and will need to be evaluated during the final design. Pending the outcome of the scour analysis, the preliminary design and depth of countersink will be revised to account for the total potential scour associated with the projected 2040 100-year flow event.

11.5 Summary

The recommended structure size of 16 foot span box culvert with an 8 foot rise and assumed 3 feet of countersink exceeds the minimum freeboard of 2 feet at the projected 2040 100-year flow event. This proposed structure allows for the channel to behave similarly through the structure as it does in the adjacent reaches under the projected 2040 100-year flow event. This will provide a robust structure design that is resilient to climate change and allow the system to function naturally, including the passage of sediment, debris and water in the future.

12.0 Scour Analysis

Scour calculations were not performed during the preliminary design, but will be performed following the procedures outlined in *Evaluating Scour at Bridges HEC No. 18* (Arneson et al. 2012) during final design. Scour components to be considered in the analysis include:

1. Long-term aggradation/degradation
2. General scour (i.e., contraction scour)
3. Local scour

In addition to the three scour components above, potential lateral migration of a channel must be assessed when evaluating total scour at highway infrastructure.

13.0 References

Aquaveo. (2019). SMS Version 13.0.8

Arneson, L.A., L.W. Zevenbergen, P.F. Lagasse, P.E. Clopper. (2012). *Evaluating Scour at Bridges – Fifth Edition*. Federal Highway Administration. Fort Collins, Colorado. Publication No. FHWA-HIF-12-003, (HEC No. 18).

Barnard, R.J., et al. (2013). *Water Crossing Design Guidelines*. Washington State Department of Fish and Wildlife. Olympia, WA

Chow, V.T., 1959, Open Channel Hydraulics, McGraw-Hill book Company, NY.

Fox, Martin and Bolton, Susan. (2007). A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forests Basins of Washington Stat. North American Journal of Fisheries Management. Vol 27, Issue 1. Pg. 342-359.

Lagasse, P.F., P.E. Clopper, J.E. Pagan-Ortiz, L.W. Zevenbergen, L.A. Arneson, J.D. Schall, L.G. Girard. (2009). *Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance-Third Edition*. Federal Highway Administration. Fort Collins, Colorado. Publication No. FHWA-NHI-09-111.

Logan, Robert L. (2003). *Geologic Map of the Shelton 1:100,000 Quadrangle, Washington.* Washington State Department of Natural Resources. Washington Division of Geology and Earth Resources Open File Report 2003-15.

Mason County GIS Department. (2013). *Contours 100 foot, Mason County, WA*. http://www.co.mason.wa.us/gis/data.php

Mastin, M.C., Konrad, C.P., Veilleux, A.G., and Tecca, A.E. (2016). Magnitude, frequency, and trends of floods at gaged and ungaged sites in Washington, based on data through water year 2014 (ver 1.2, November 2017): U.S. Geological Survey Scientific Investigations Report 2016-5118, 70p.

PRISM Climate Group. Oregon State University. http://prism.oregonstate.edu

StreamNet. 2017. Pacific Northwest salmonid and critical habitat distribution. StreamNet, Portland, OR. http://www.streamnet.org/

United States Department of Agriculture. (2001) Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring.

United States Department of Agriculture, Forest Service. (2008) Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings, Appendix E.

United States Department of the Interior, Bureau of Reclamation. (2017). SRH-2D Version 3.2.0.

United States Geological Survey. (2014). “StreamStats in Washington.” http://water.usgs.gov/osw/streamstats/Washington.html (August 2019)

United States Department of the Interior, Bureau of Reclamation (USBR). 1984. “Computing Degradation and Local Scour, Technical Guideline for Bureau of Reclamation.” Denver, CO.

Washington State Department of Transportation (2012). *Standard Specifications for Road, Bridge, and Municipal Construction*. Washington State Department of Transportation. Olympia, WA. Publication Number M 41-10.

WDFW (Washington State Department of Fish and Wildlife). 2019a. Priority Habitats and Species map. Accessed September 2019.

WDFW (Washington State Department of Fish and Wildlife). 2019b. SalmonScape. http://wdfw.wa.gov/mapping/salmonscape. Accessed September 2019.

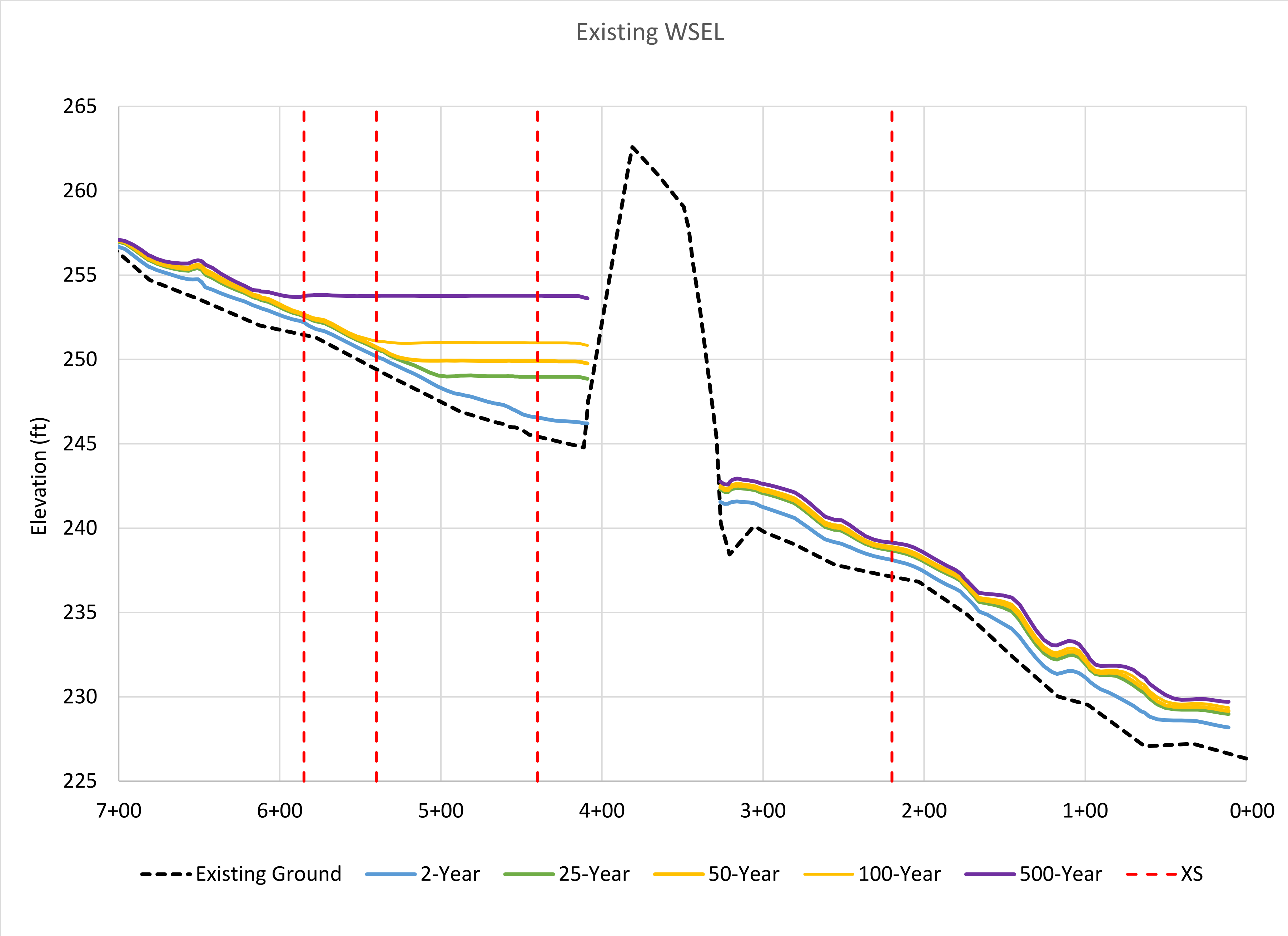
14.0 Appendices

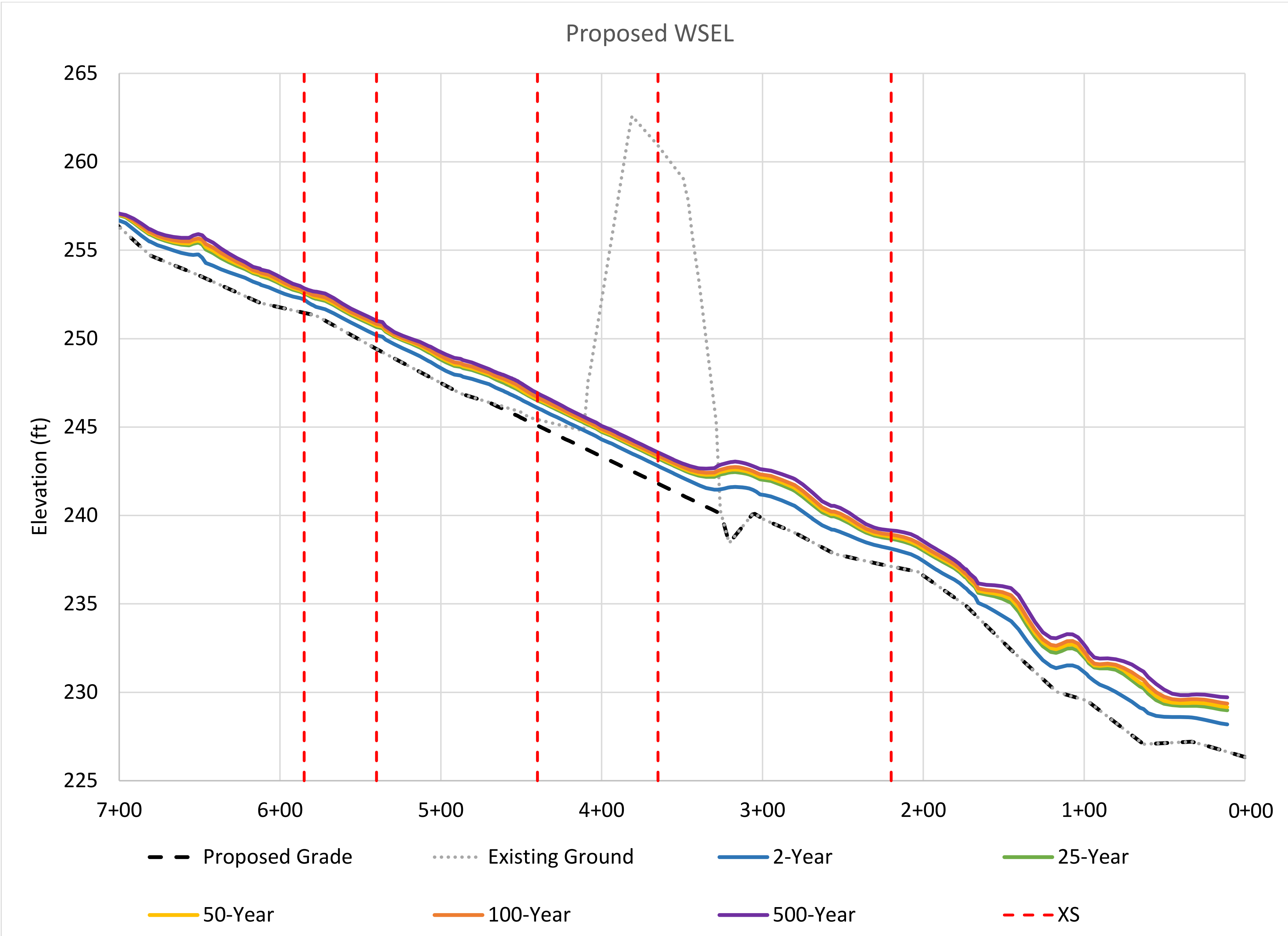
Appendix A – SRH-2D Model Results

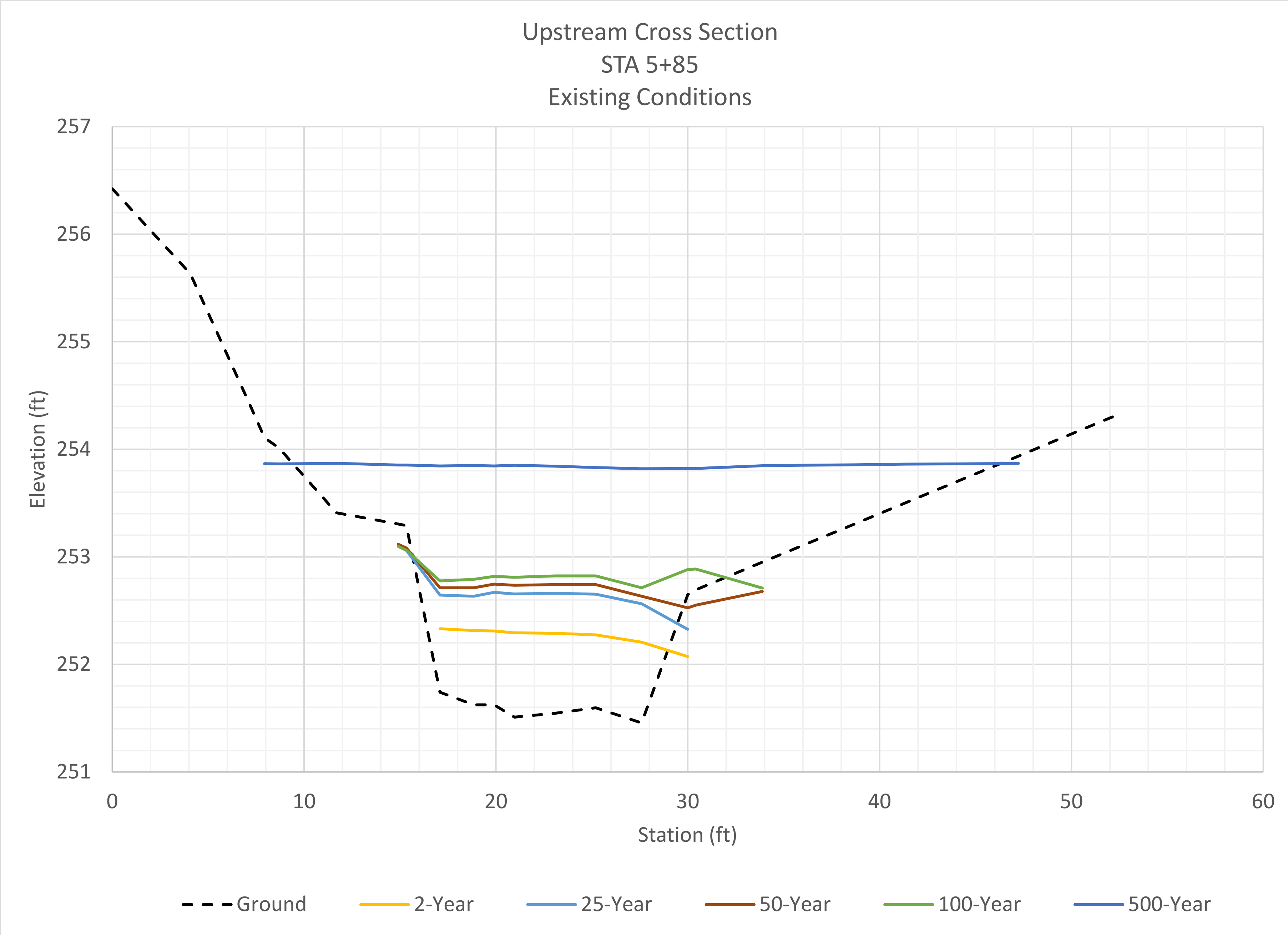
Appendix B – Stream Plan Sheets, Profile, Details

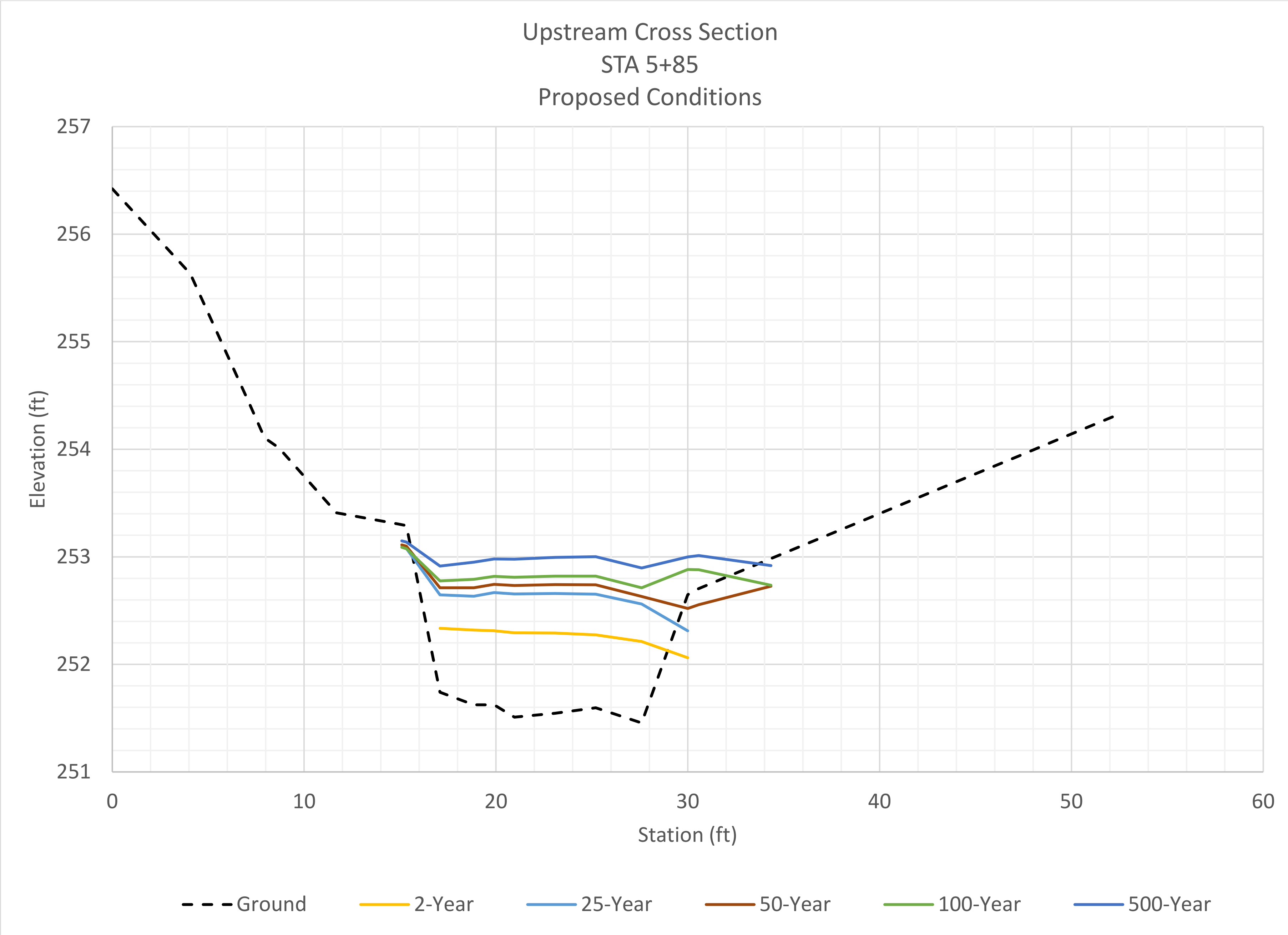
Appendix C – WDFW Future Projections for Climate-Adapted Culvert Design Printout

Appendix A – SRH-2D Model Results

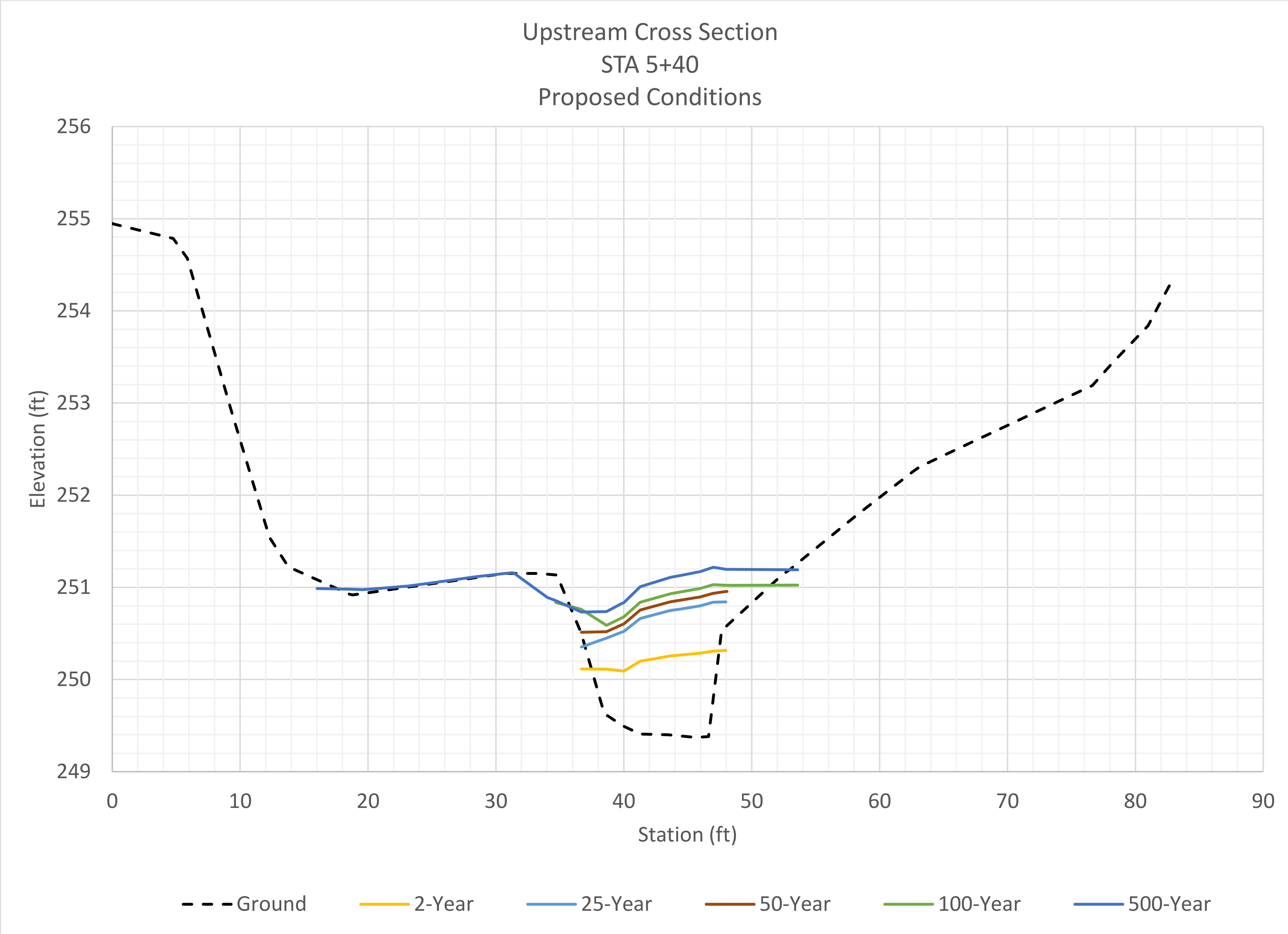

Existing WSEL
265
260
255
250
245
240
235
230
225
Elevation (ft)
7+00
6+00
5+00
4+00
3+00
2+00
1+00
0+00
Existing Ground
2-Year
25-Year
50-Year
100-Year
500-Year
XS


Proposed WSEL
Elevation (ft)
265
260
255
250
245
240
235
230
225
7+00
6+00
5+00
4+00
3+00
2+00
1+00
0+00
Proposed Grade
Existing Ground
2-Year
25-Year
50-Year
100-Year
500-Year
XS

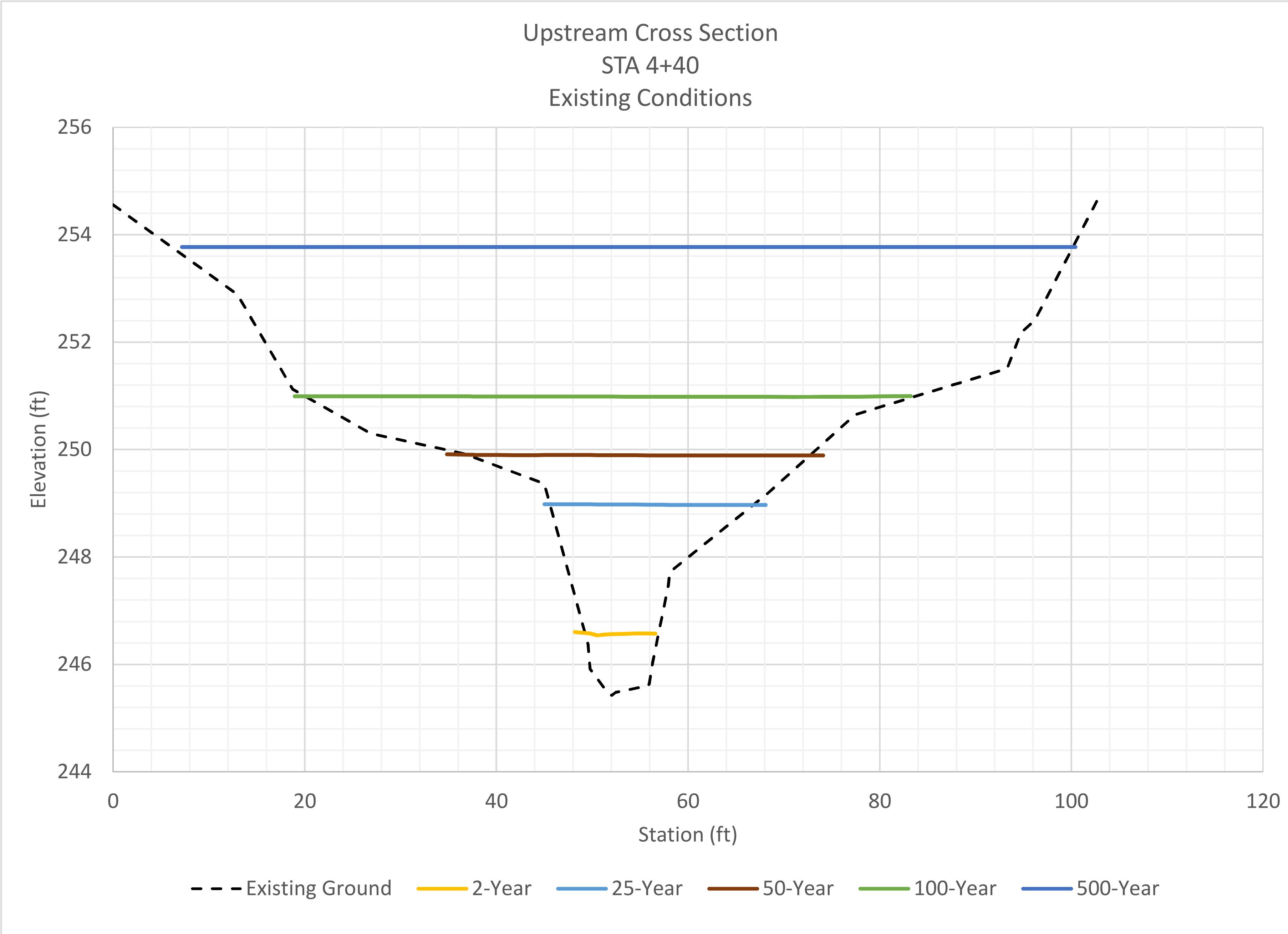

Upstream Cross Section
STA 5+85
Existing Conditions
Elevation (ft)
257
256
255
254
253
252
251
0
10
20
30
40
50
60
Station (ft)
Ground
2-Year
25-Year
50-Year
100-Year
500-Year


Upstream Cross Section
STA 5+85
Proposed Conditions
Elevation (ft)
257
256
255
254
253
252
251
0
10
20
30
40
50
60
Station (ft)
Ground
2-Year
25-Year
50-Year
100-Year
500-Year


Upstream Cross Section
STA 5+40
Existing Conditions
Elevation (ft)
256
255
254
253
252
251
250
249
0
10
20
30
40
50
60
70
80
90
Station (ft)
Ground
2-Year
25-Year
50-Year
100-Year
500-Year



Upstream Cross Section
STA 5+40
Proposed Conditions
Elevation (ft)
256
255
254
253
252
251
250
249
0
10
20
30
40
50
60
70
80
90
Station (ft)
Ground
2-Year
25-Year
50-Year
100-Year
500-Year


Upstream Cross Section
STA 4+40
Existing Conditions
Elevation (ft)
256
254
252
250
248
246
244
0
20
40
60
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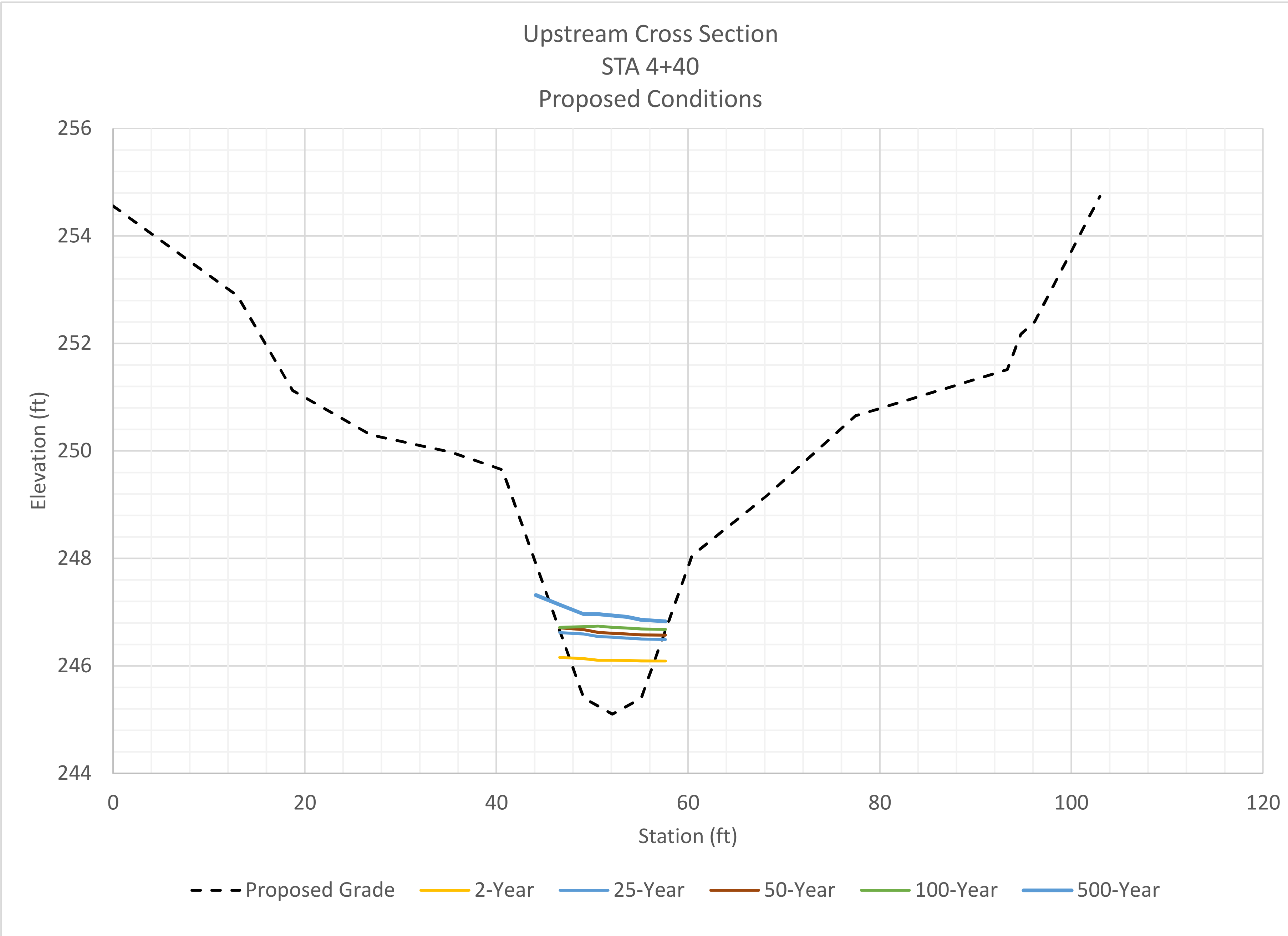
25-Year
50-Year
100-Year
500-Year


Upstream Cross Section
STA 4+40
Proposed Conditions
Elevation (ft)
256
254
252
250
248
246
244
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20
40
60
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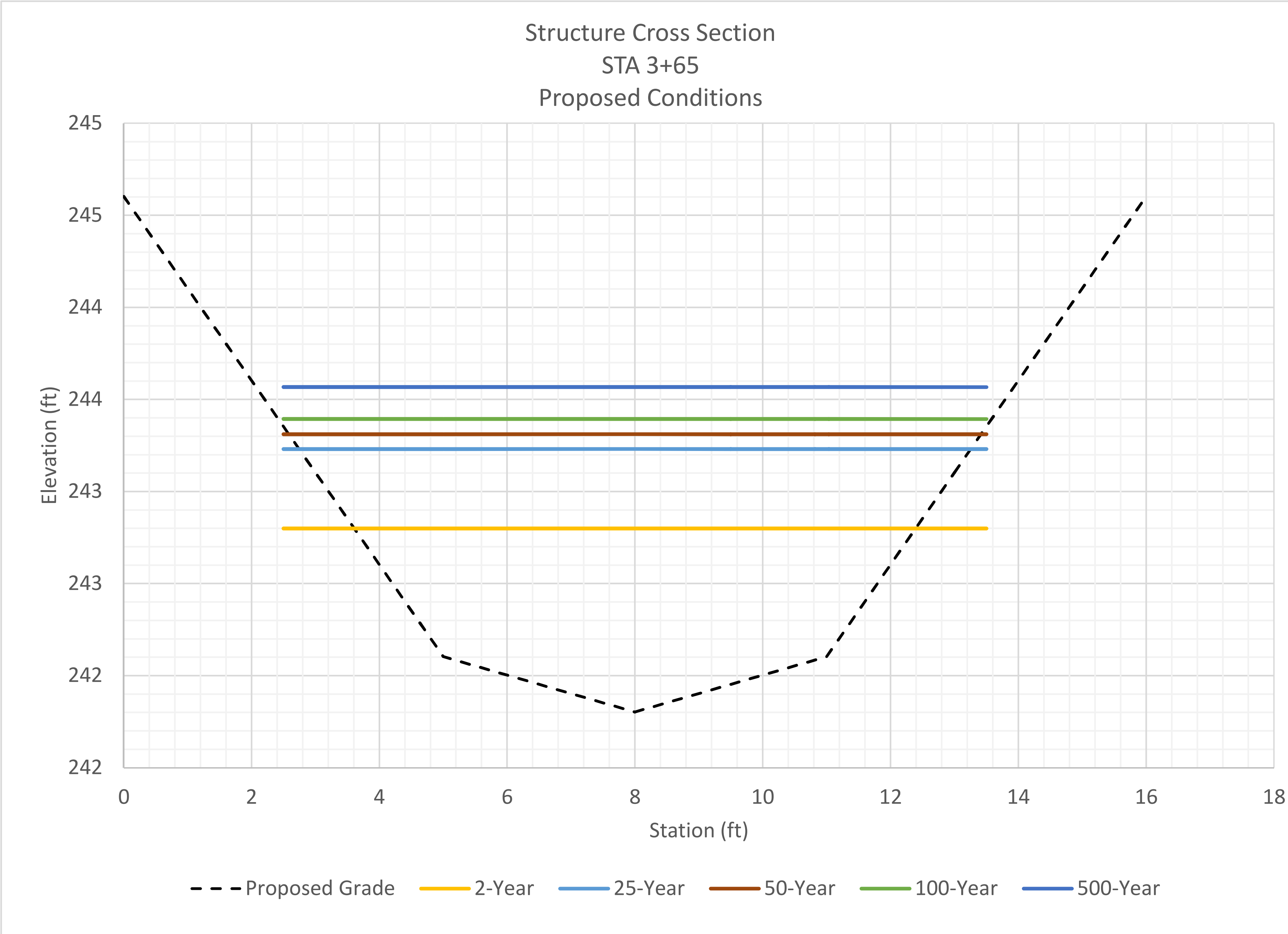
50-Year
100-Year
500-Year



Structure Cross Section
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Proposed Conditions
Elevation (ft)
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245
244
244
243
243
242
242
Station (ft)
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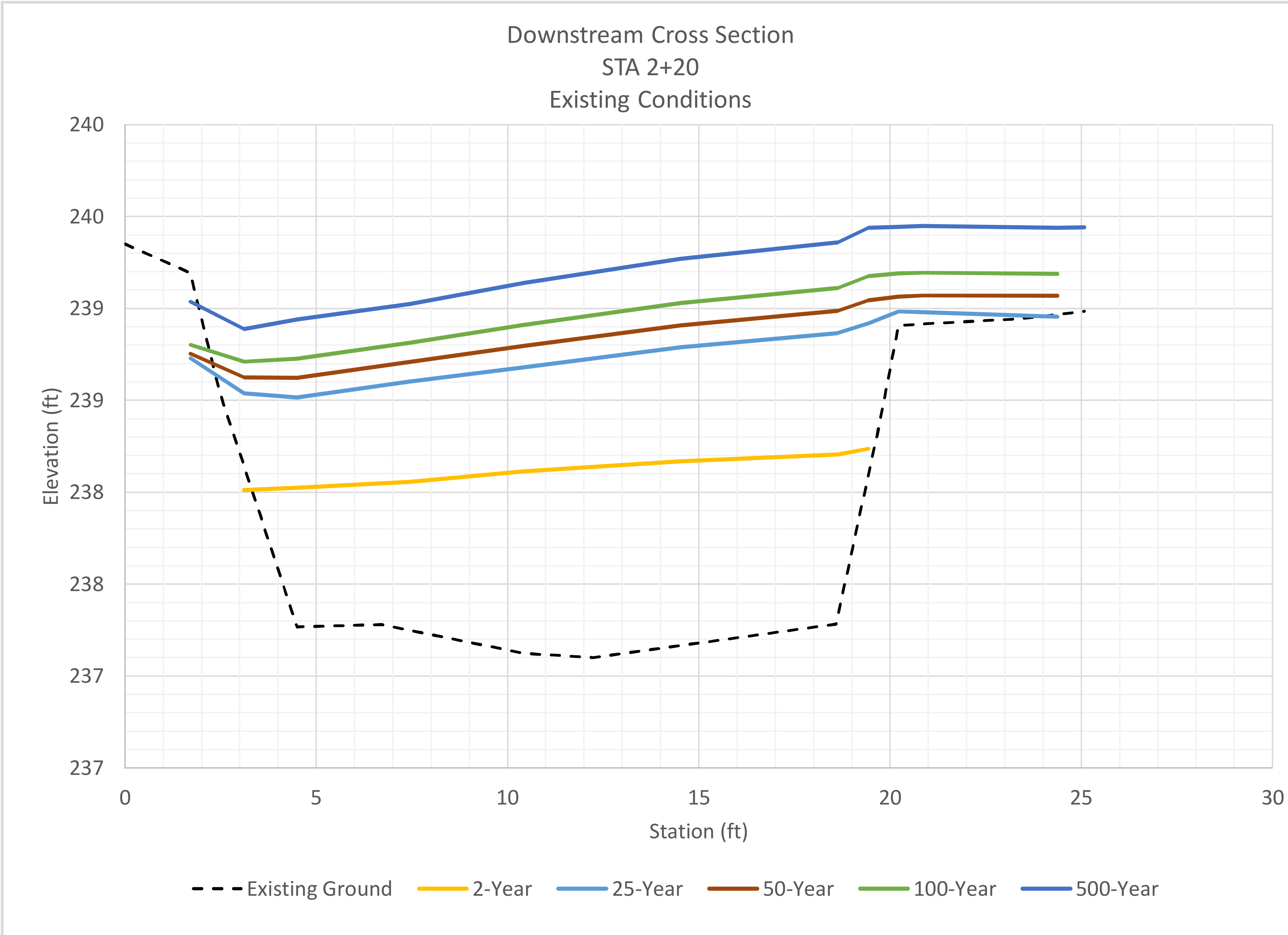
2
4
6
8
10
12
14
16
18
Proposed Grade
2-Year
25-Year
50-Year
100-Year
500-Year



Downstream Cross Section
STA 2+20
Existing Conditions
240
240
239
239
238
238
237
237
0
5
10
15
20
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Station (ft)
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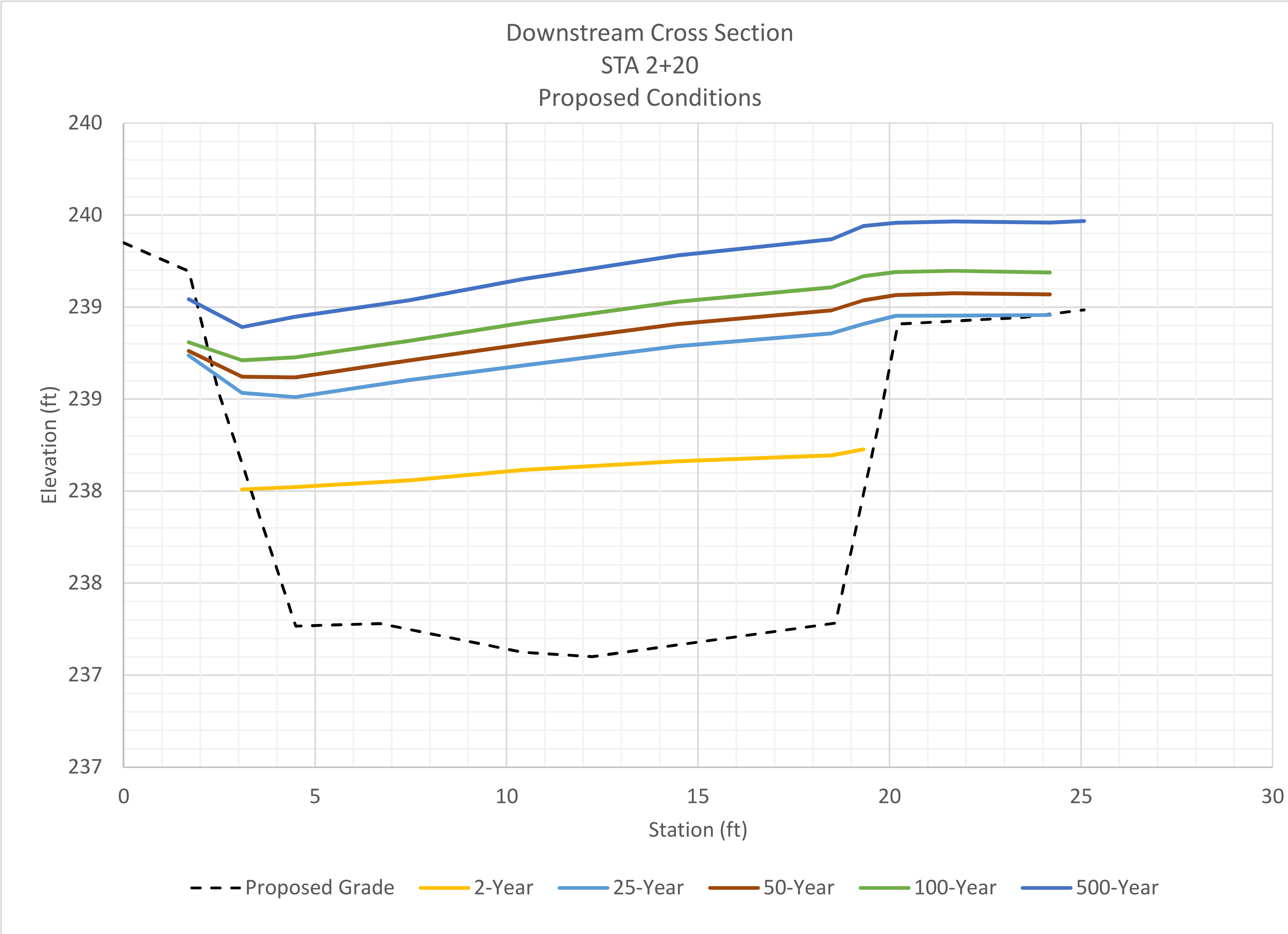
50-Year
100-Year
500-Year



Downstream Cross Section
STA 2+20
Proposed Conditions
240
240
239
239
238
238
237
237
Elevation (ft)
0
5
10
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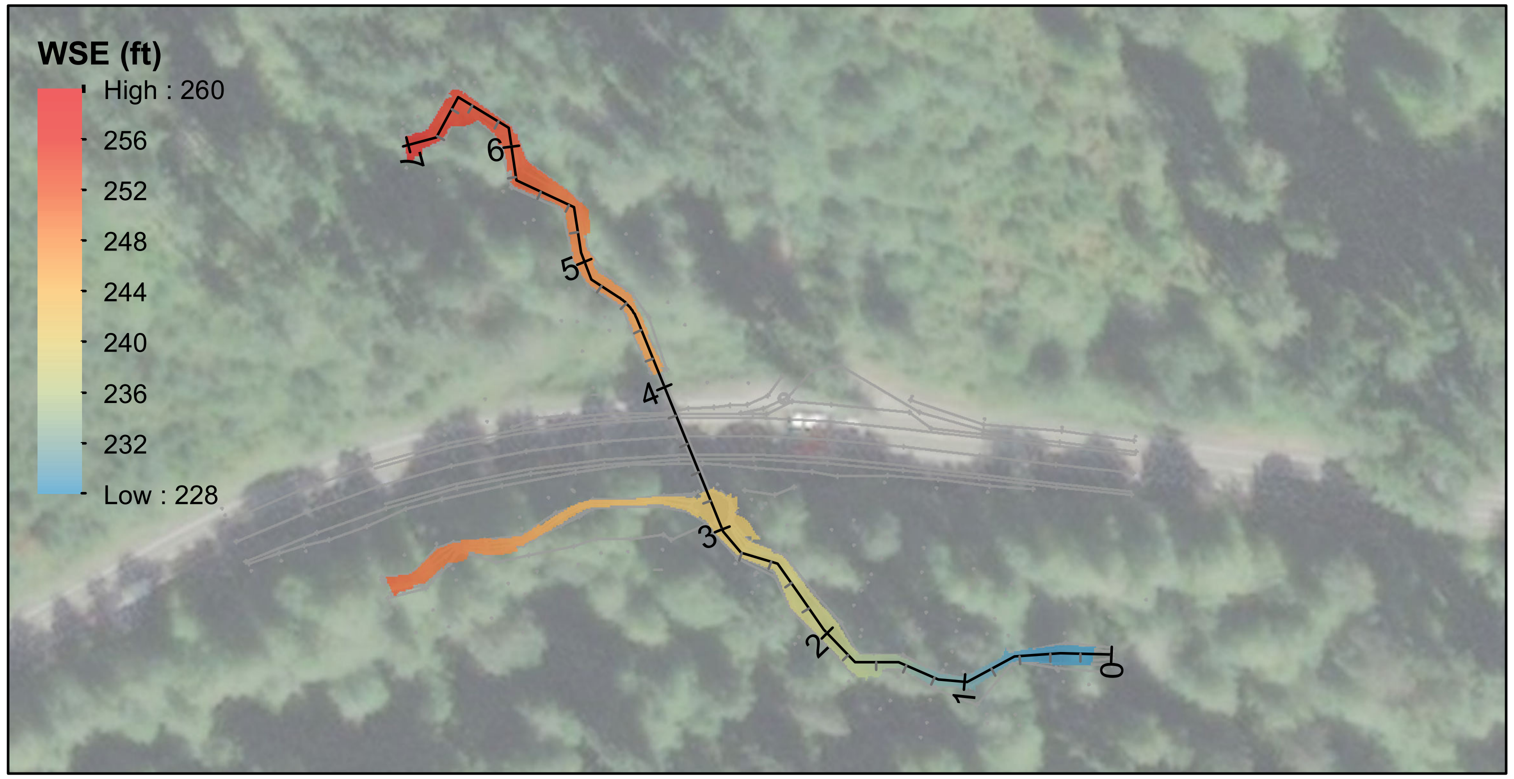
50-Year
100-Year
500-Year



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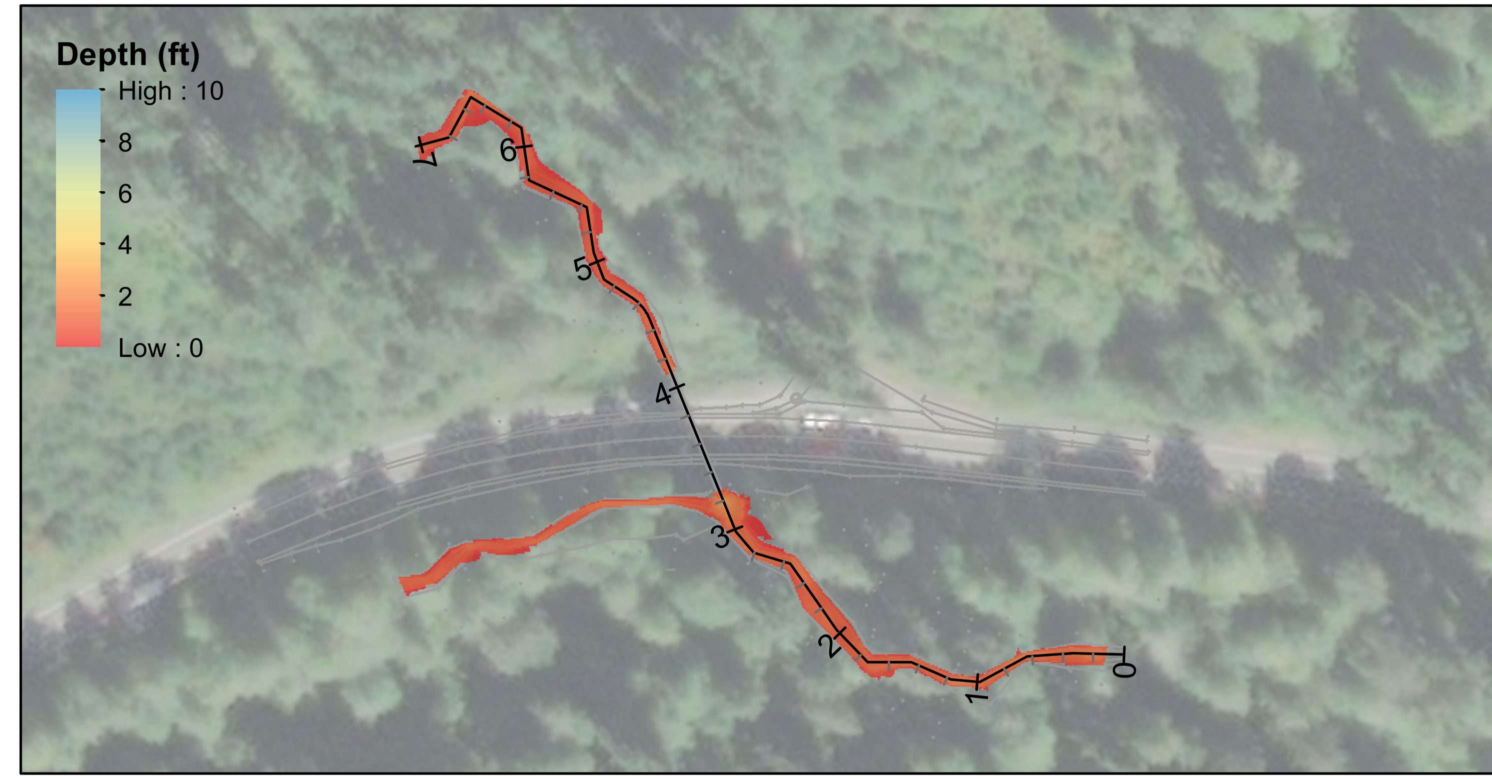
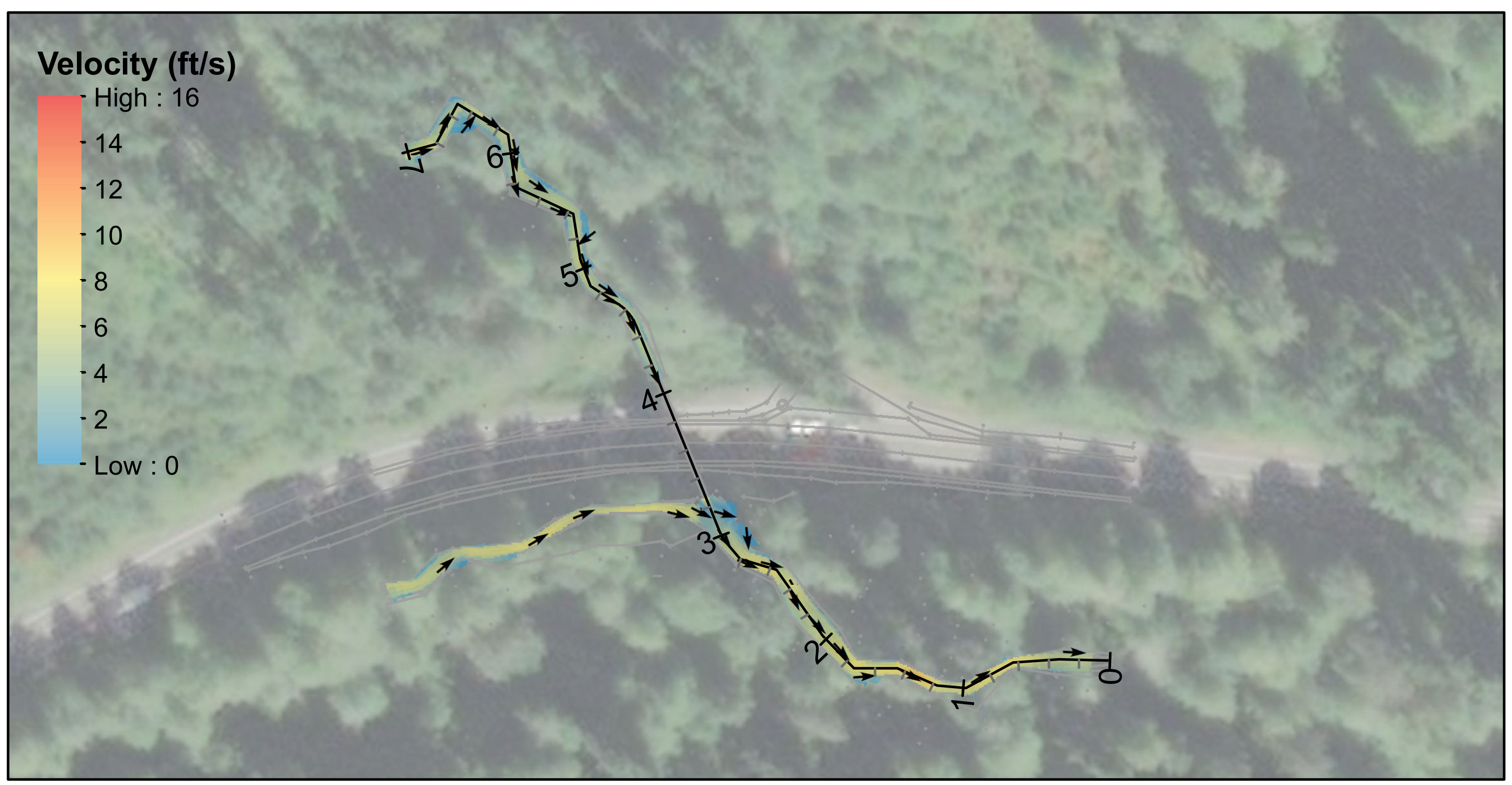
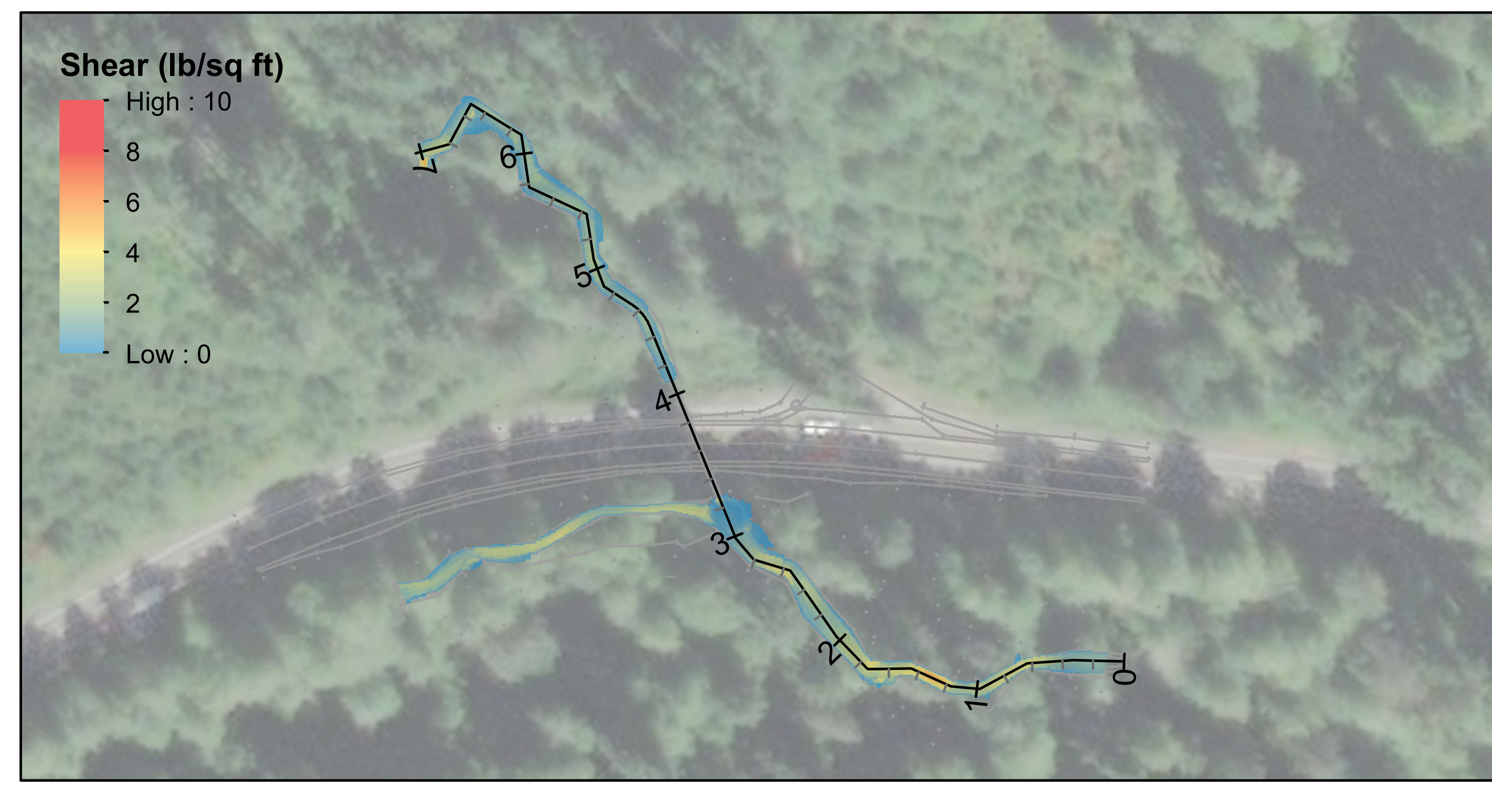


DEPTH



VELOCITY



SHEAR

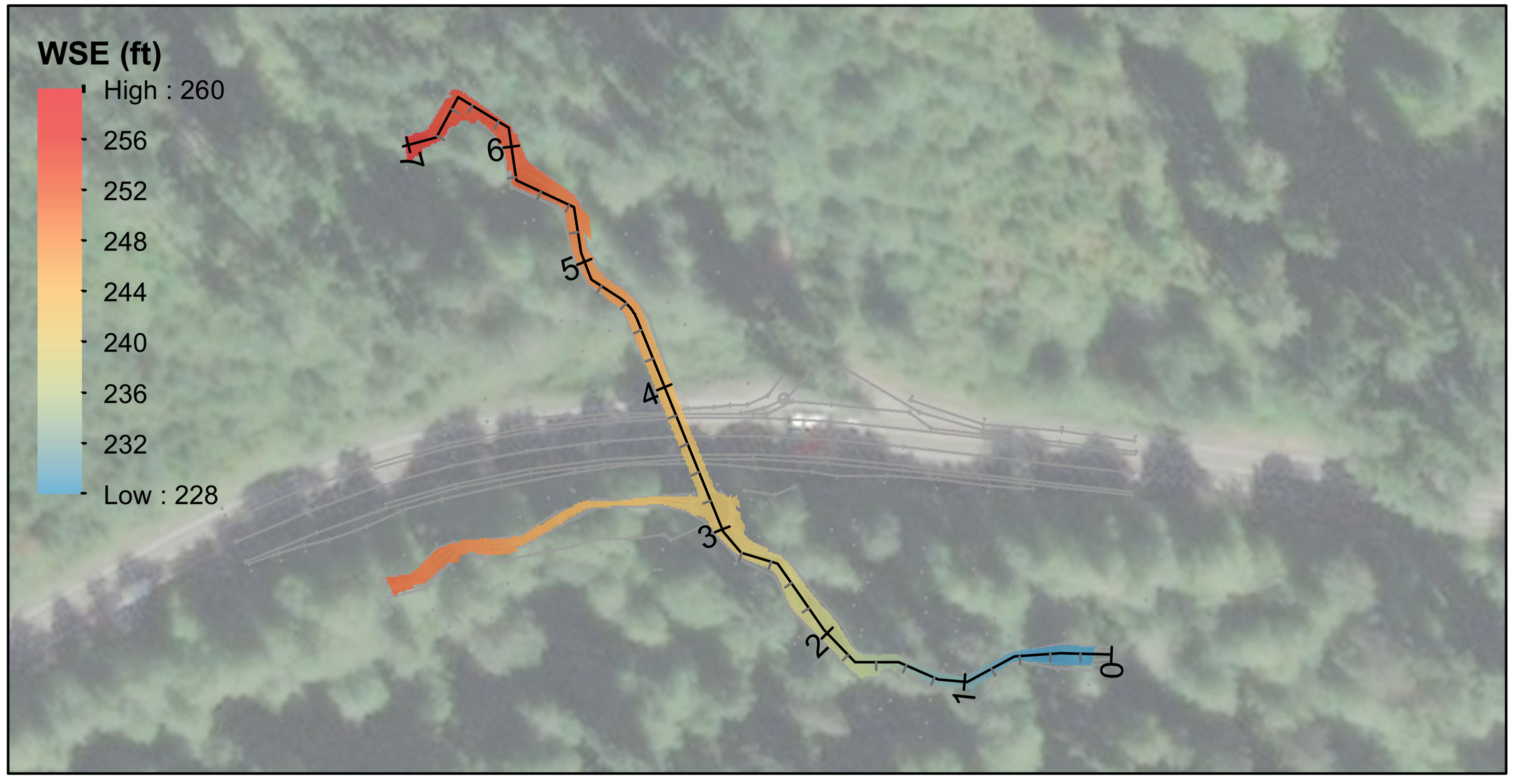
N

0 75 150 Feet

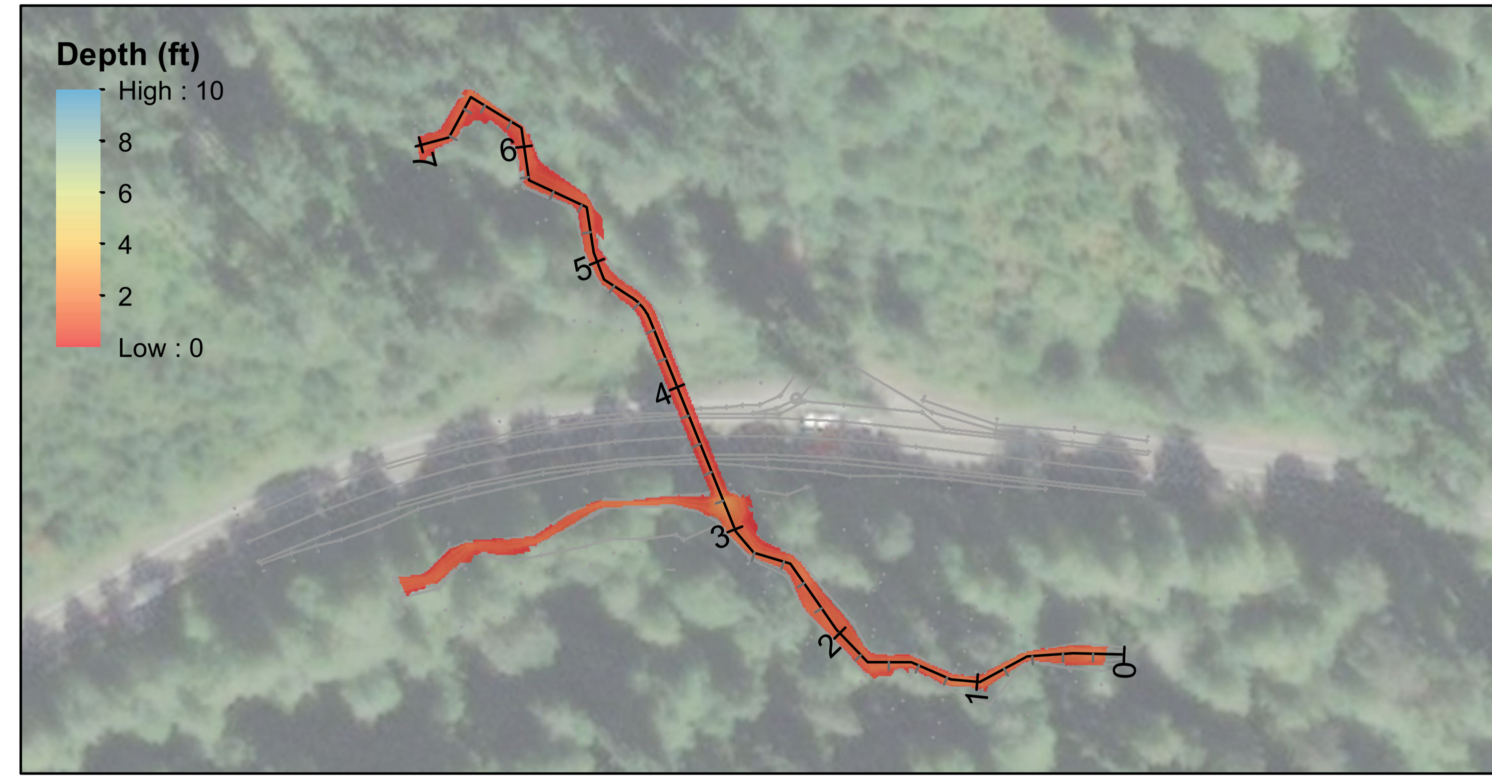
Washington State Department of Transportation

EXISTING CONDITIONS - 2 YEAR EVENT

SR 108 UNNAMED TRIBUTARY TO SKOOKUM
MP 5.5



WATER SURFACE ELEVATION



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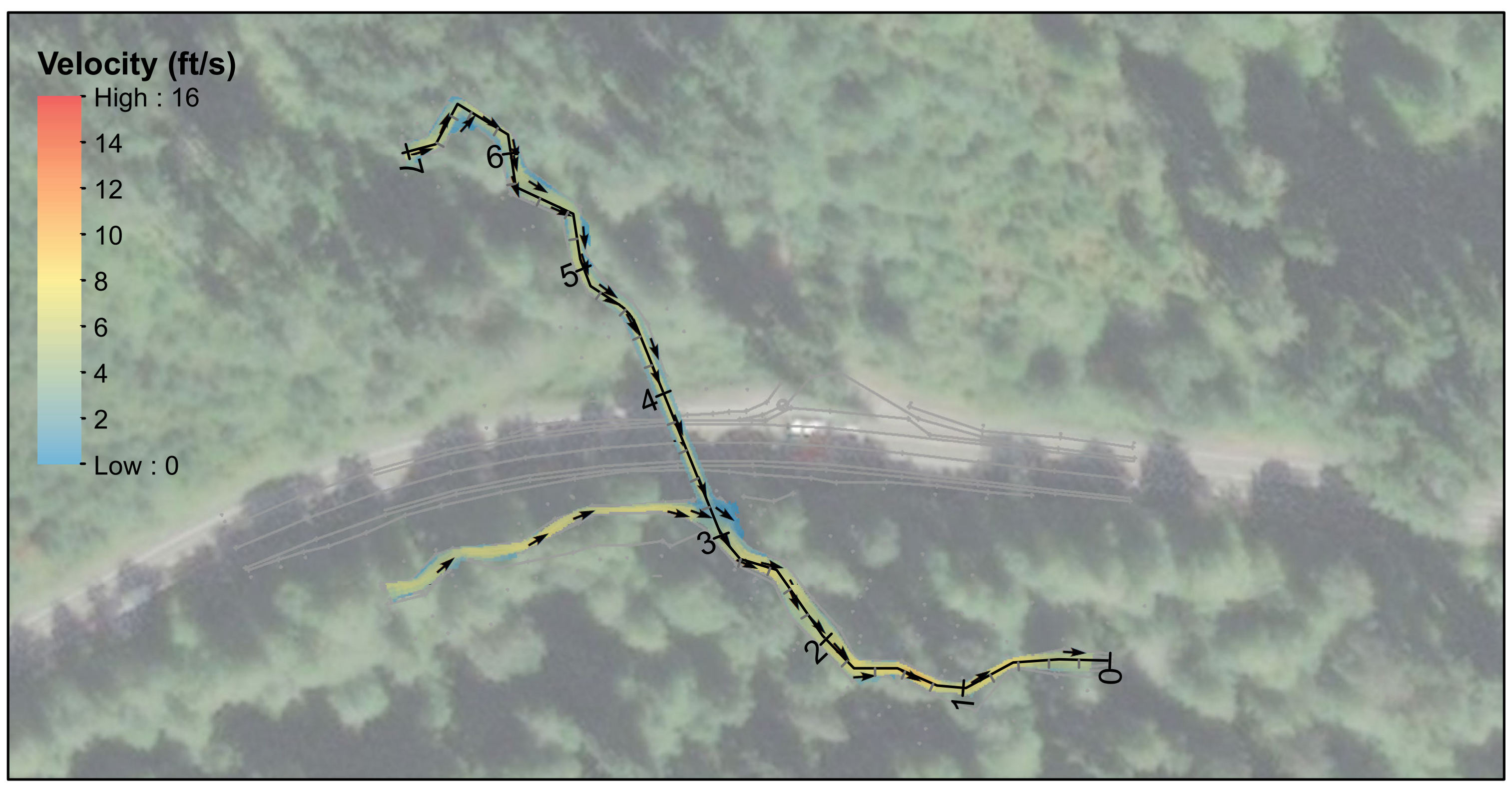

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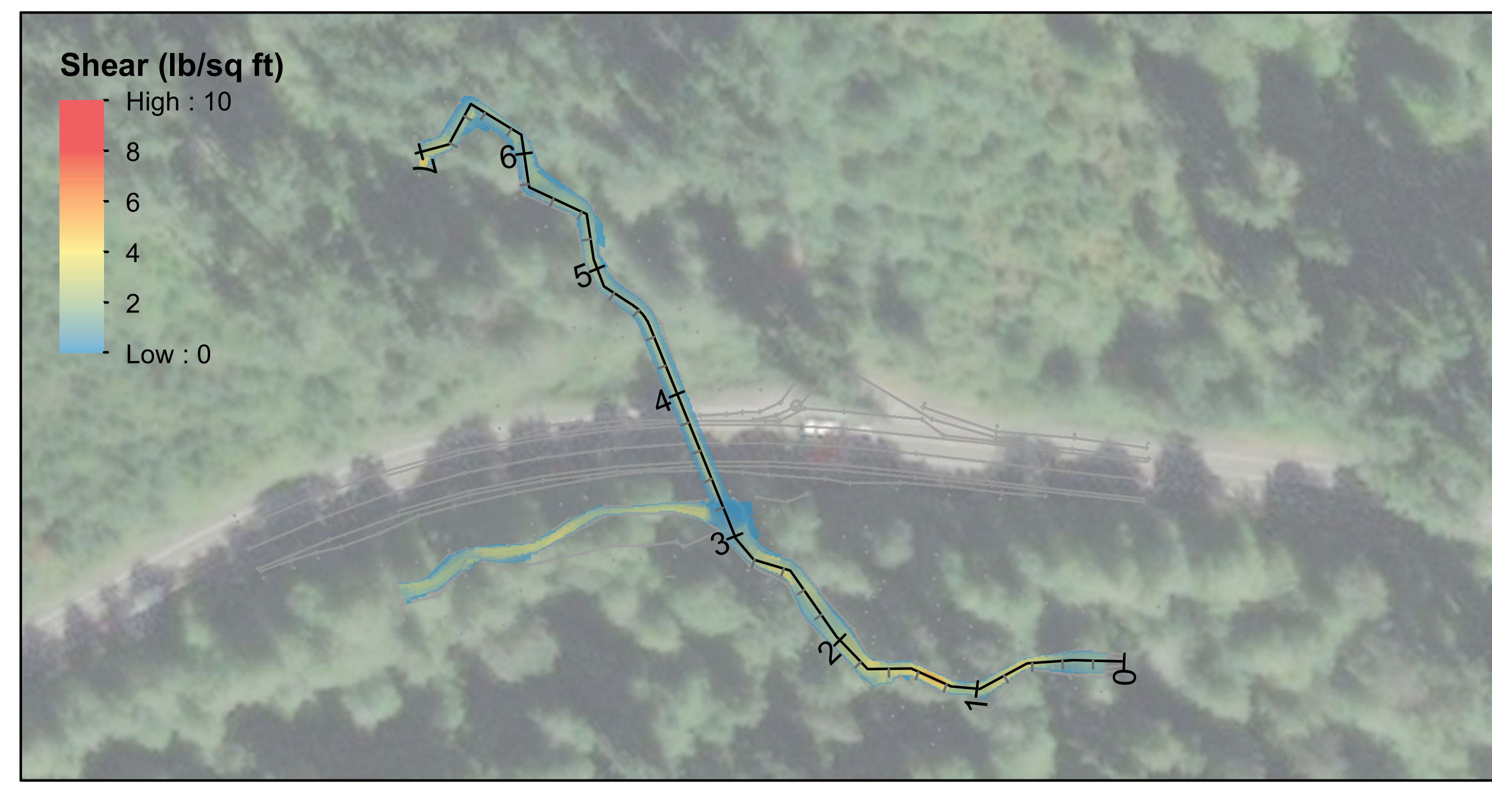

SHEAR

N

0 75 150 Feet

HDR

Washington State Department of Transportation

PROPOSED CONDITIONS - 2 YEAR EVENT

SR 108 UNNAMED TRIBUTARY TO SKOOKUM
MP 5.5

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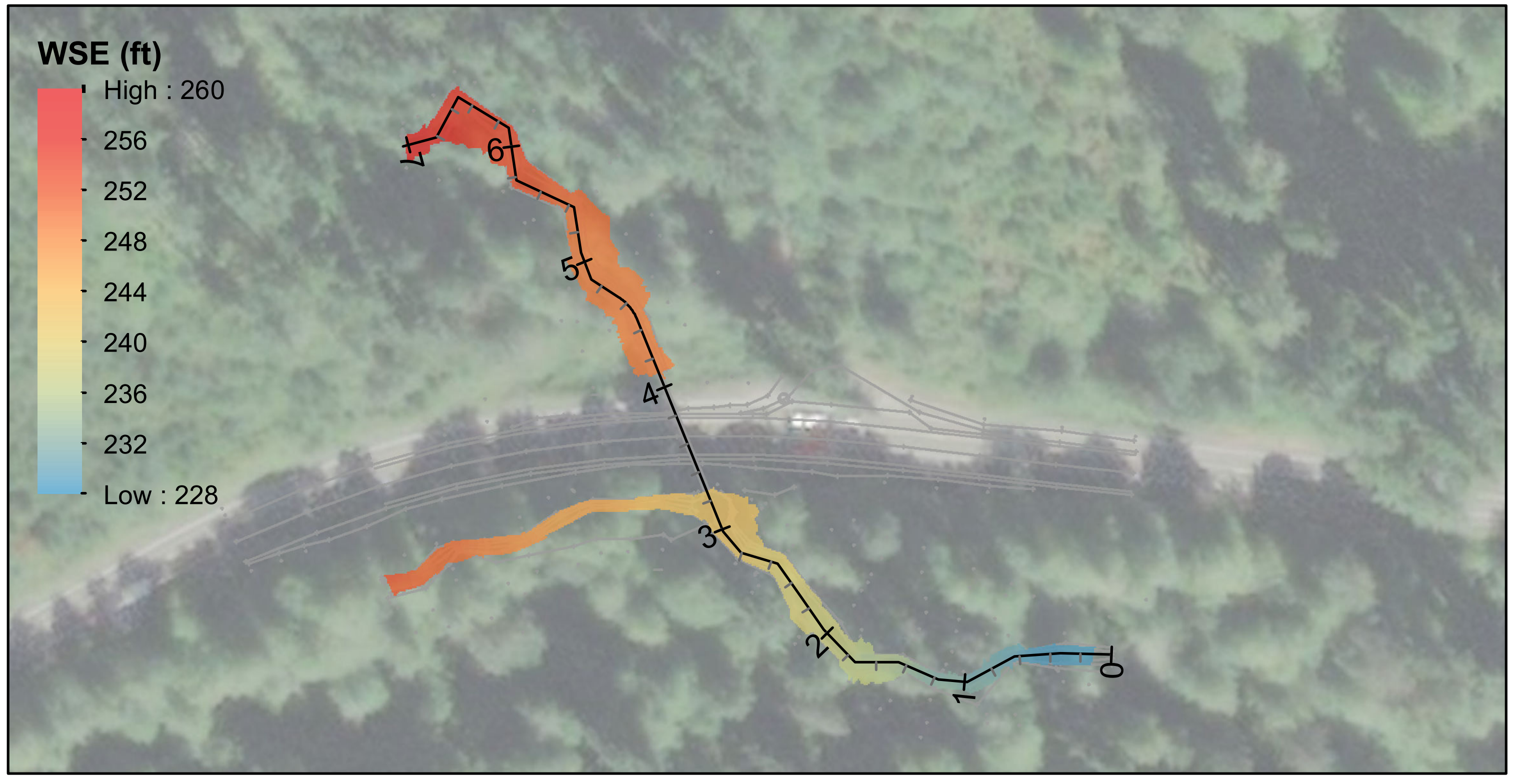


WATER SURFACE ELEVATION

DEPTH

VELOCITY

SHEAR

N

0 75 150 Feet

Washington State Department of Transportation

EXISTING CONDITIONS - 25 YEAR EVENT

SR 108 UNNAMED TRIBUTARY TO SKOOKUM
MP 5.5

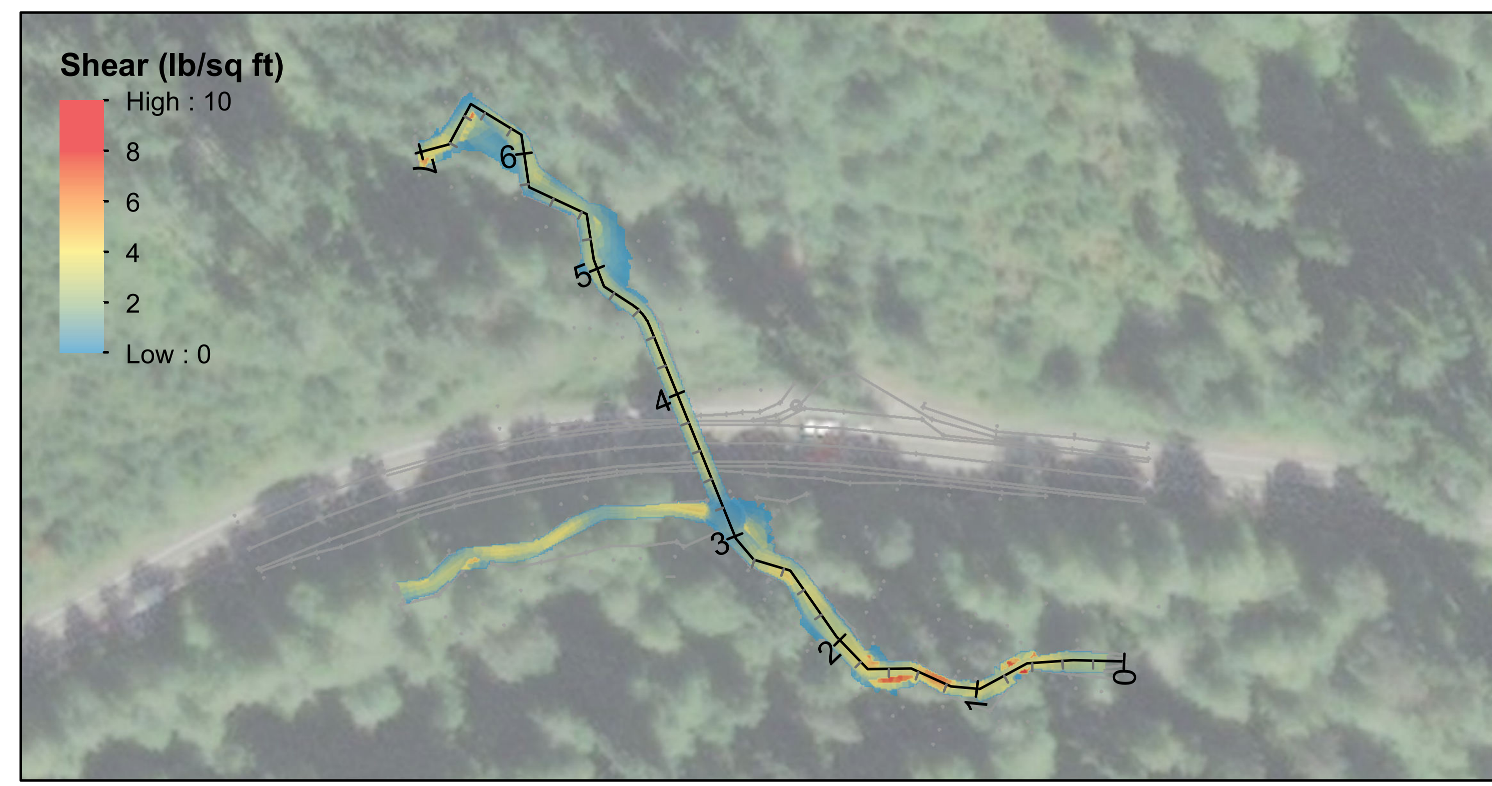
PATH: S:\SR108\MP5.5 WDFW ID 991237 UNT TO SKOOKUM\RESULTS\OUTPUT FIGURES\EXISTING_25YR FINAL.MXD - USER: DMINNER - DATE: 10/2/2019

PRELIMINARY HYDARULIC DESIGN

WATER SURFACE ELEVATION

DEPTH

VELOCITY



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Washington State Department of Transportation

PROPOSED CONDITIONS - 25 YEAR EVENT

SR 108 UNNAMED TRIBUTARY TO SKOOKUM
MP 5.5

PATH: S:\SR108\MP5.5 WDFW ID 991237 UNT TO SKOOKUM\RESULTS\OUTPUT FIGURES\PROPOSED_25YR FINAL.MXD - USER: DMINNER - DATE: 10/2/2019

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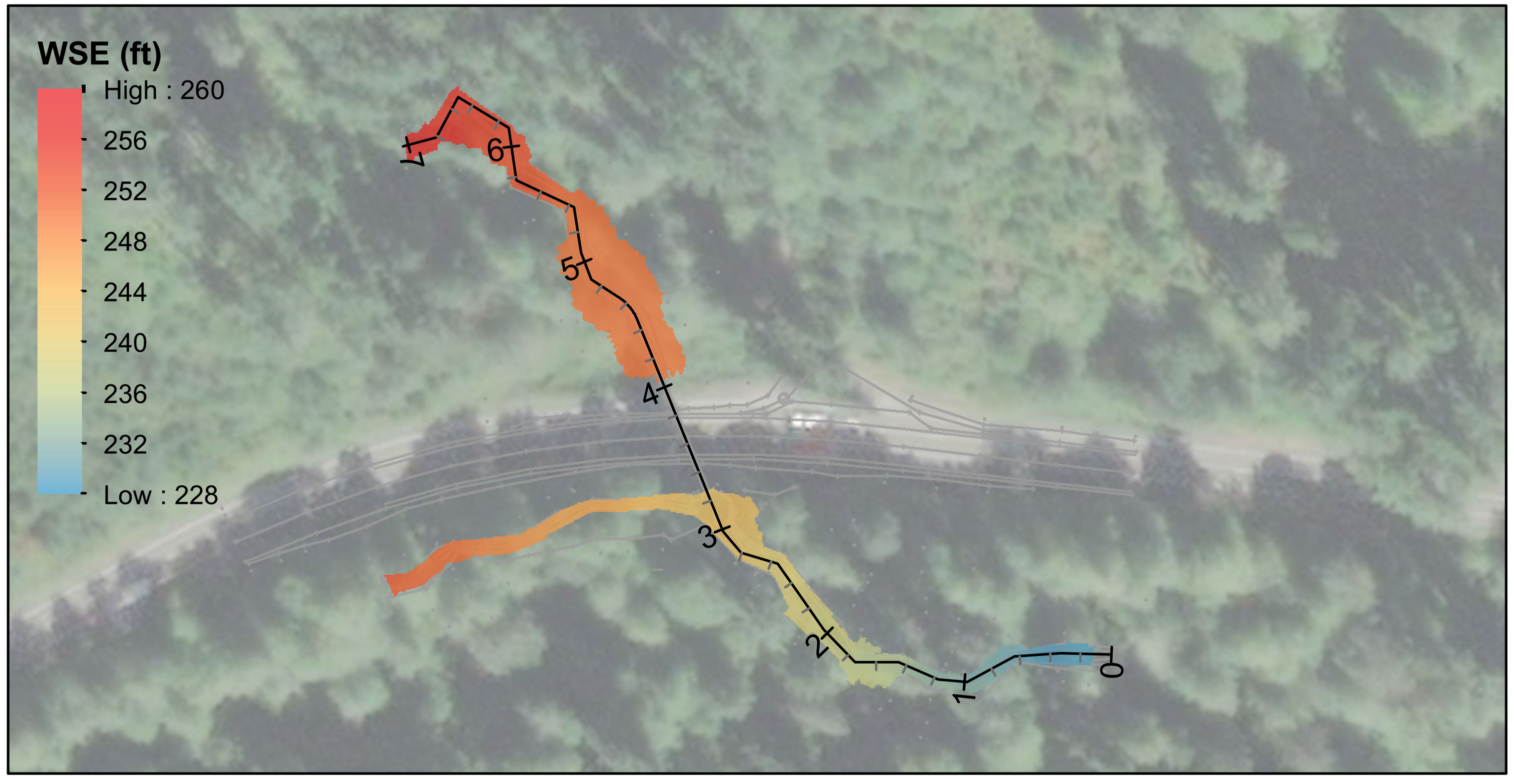
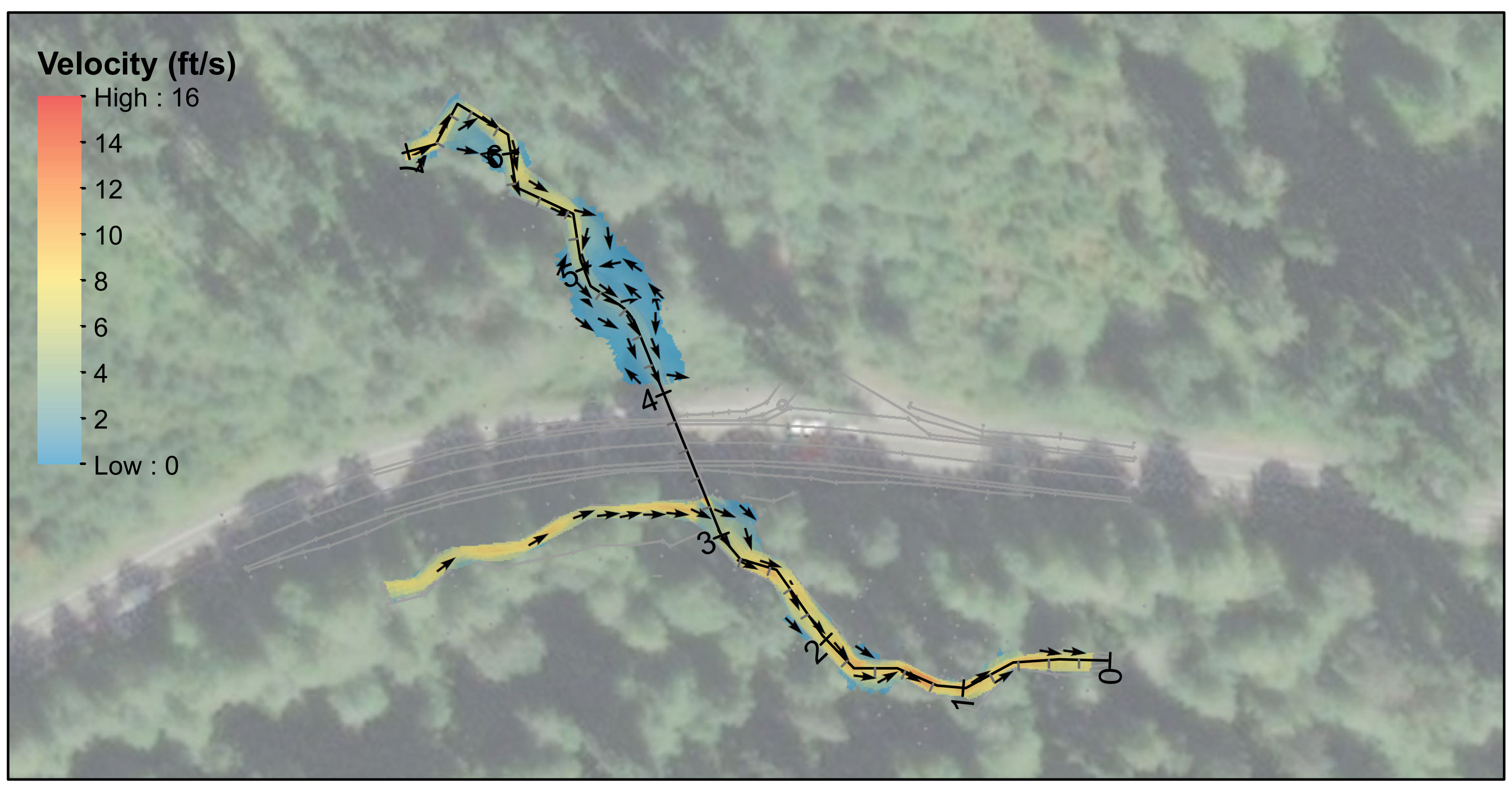


WATER SURFACE ELEVATION

DEPTH



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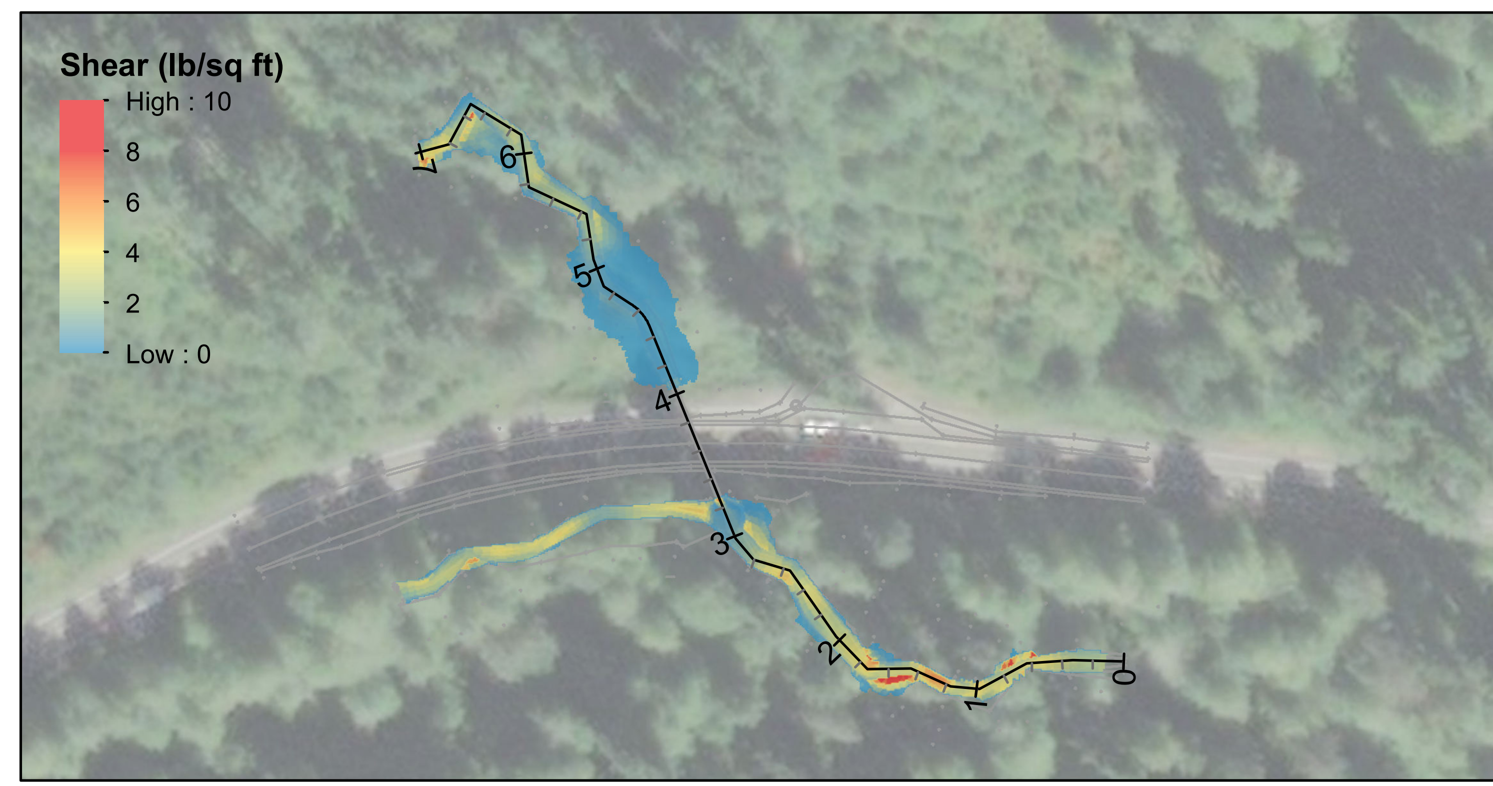

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0 75 150 Feet

Washington State Department of Transportation

EXISTING CONDITIONS - 50 YEAR EVENT

SR 108 UNNAMED TRIBUTARY TO SKOOKUM
MP 5.5

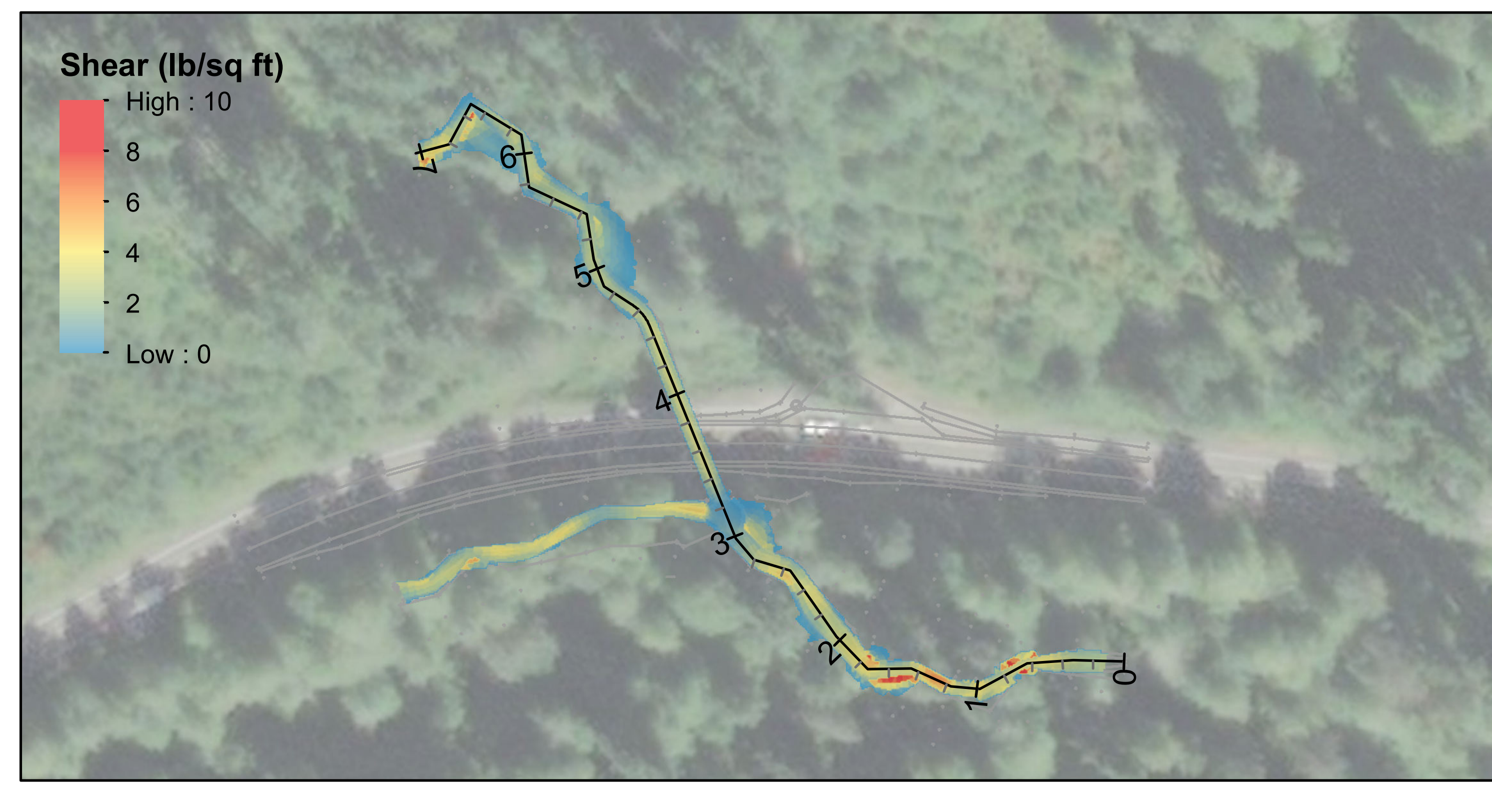
PATH: S:\SR108\MP5.5 WDFW ID 991237 UNT TO SKOOKUM\RESULTS\OUTPUT FIGURES\EXISTING_50YR FINAL.MXD - USER: DMINNER - DATE: 10/2/2019

PRELIMINARY HYDARULIC DESIGN

WATER SURFACE ELEVATION

DEPTH

VELOCITY



SHEAR

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Washington State Department of Transportation

PROPOSED CONDITIONS - 50 YEAR EVENT

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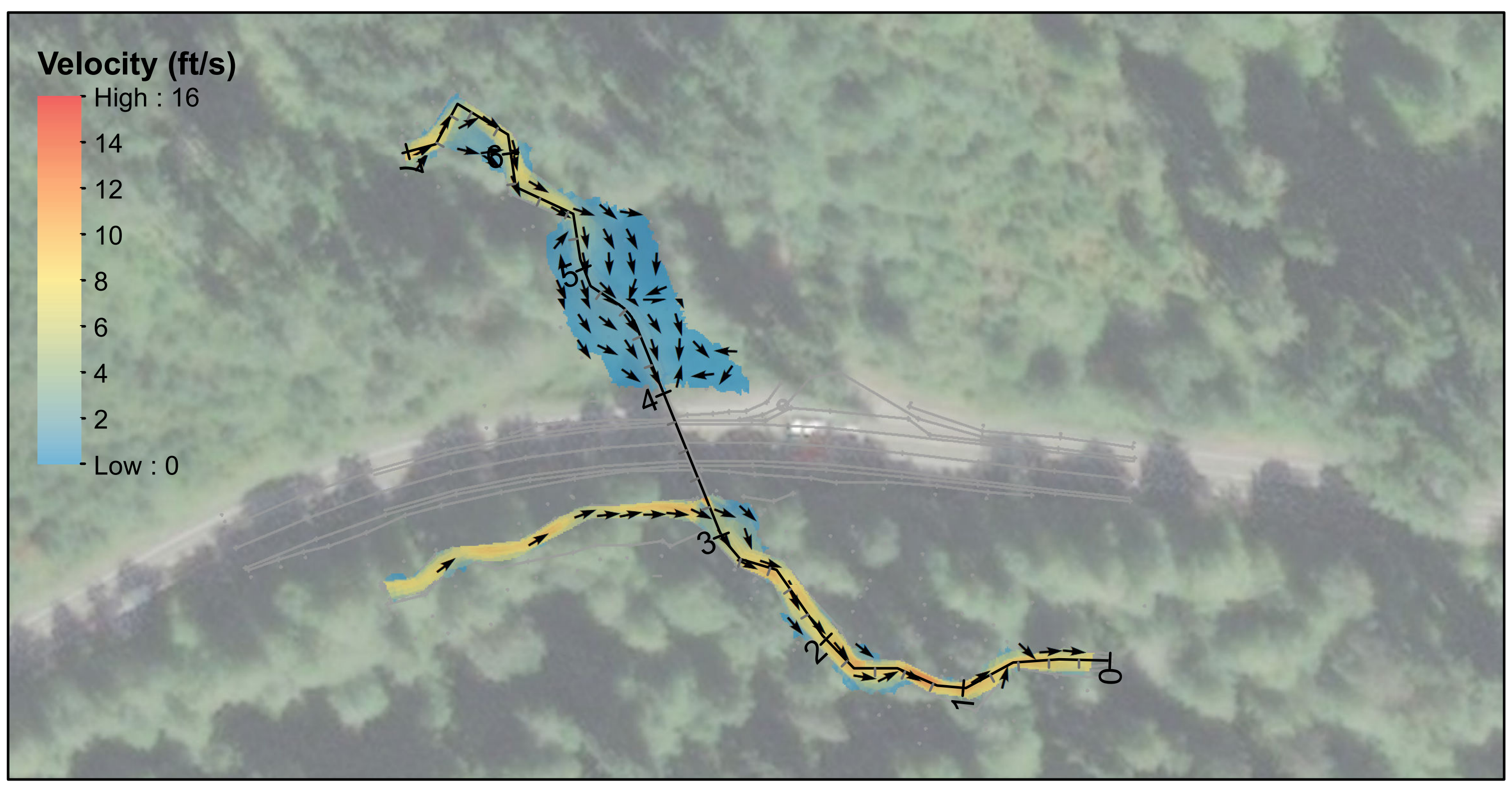
MP 5.5

PATH: S:\SR108\MP5.5 WDFW ID 991237 UNT TO SKOOKUM\RESULTS\OUTPUT FIGURES\PROPOSED_50YR FINAL.MXD - USER: DMINNER - DATE: 10/2/2019

PRELIMINARY HYDARULIC DESIGN

WATER SURFACE ELEVATION

DEPTH



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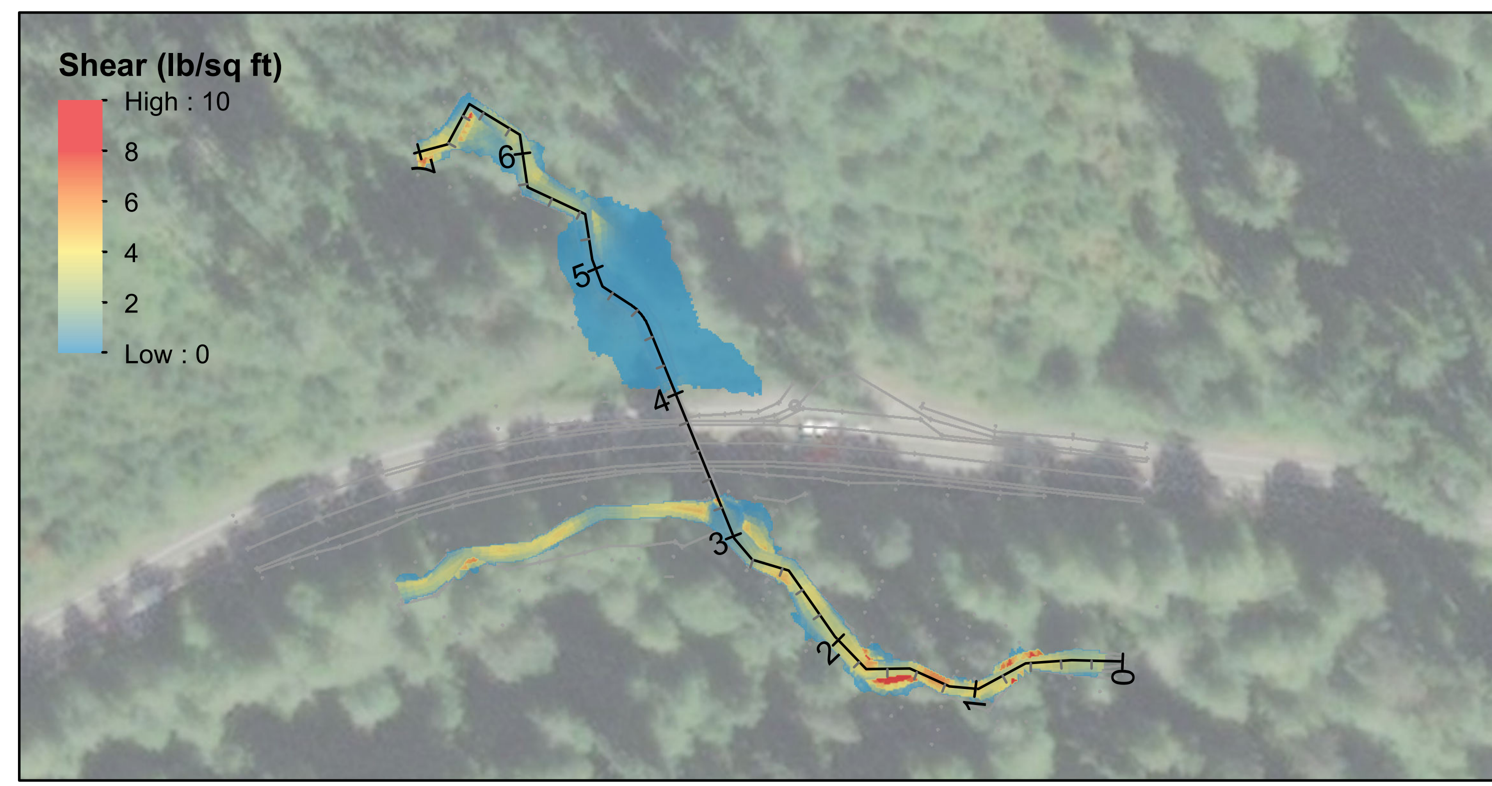

SHEAR

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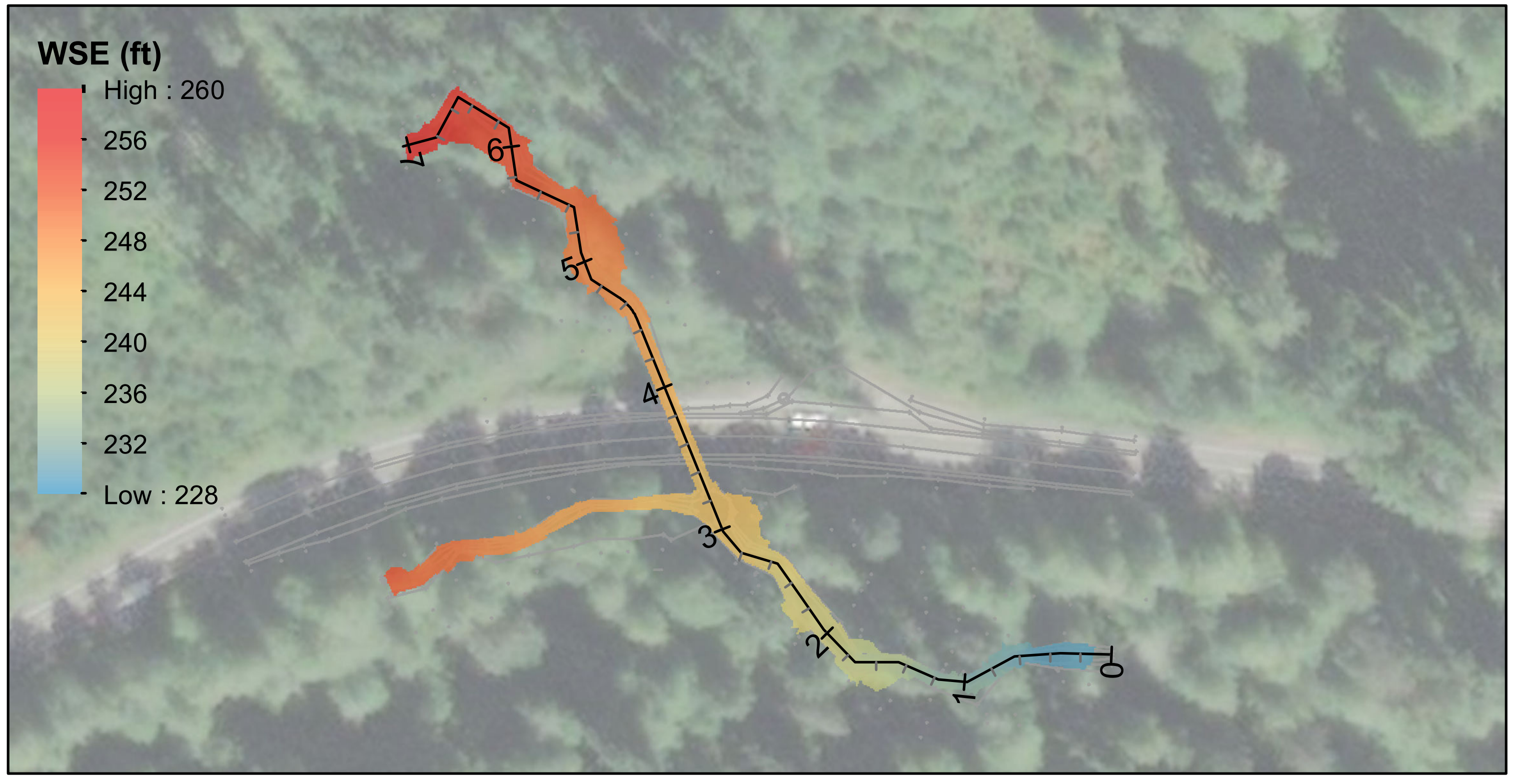
0 75 150 Feet

Washington State Department of Transportation

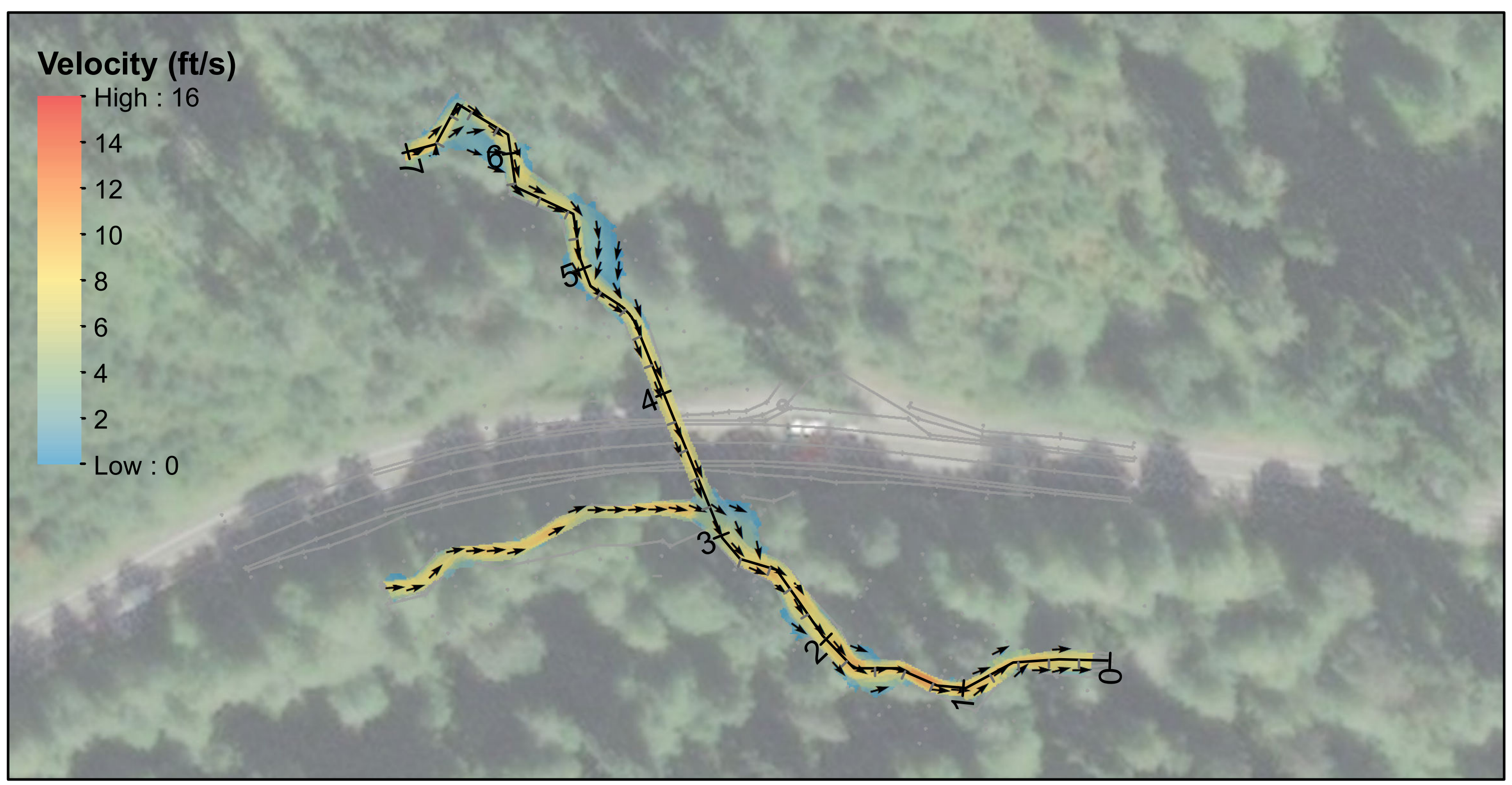
EXISTING CONDITIONS - 100 YEAR EVENT

SR 108 UNNAMED TRIBUTARY TO SKOOKUM
MP 5.5



WATER SURFACE ELEVATION

DEPTH



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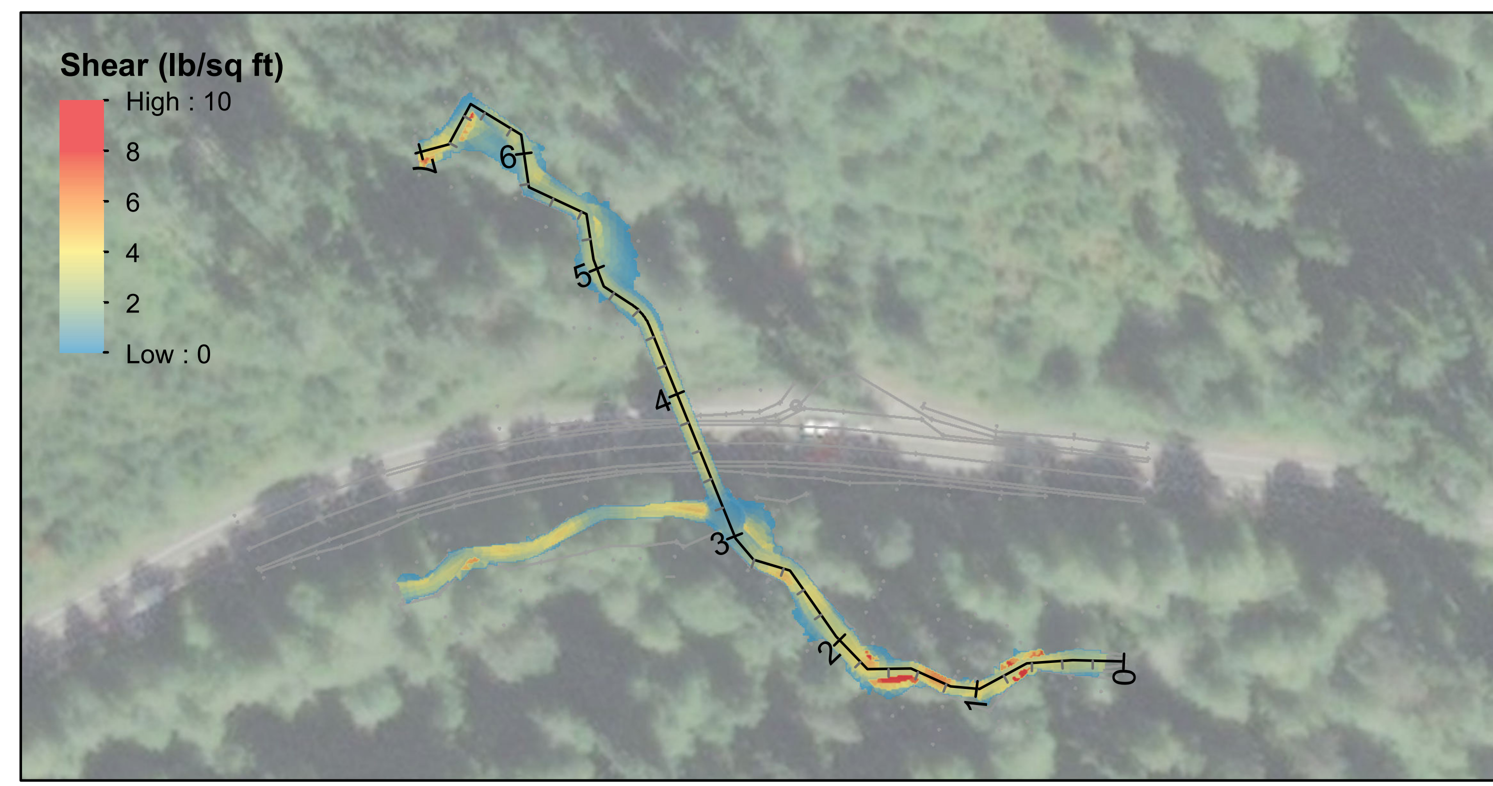

SHEAR

N

0 75 150 Feet

Washington State Department of Transportation

SR 108 UNNAMED TRIBUTARY TO SKOOKUM
MP 5.5

PROPOSED CONDITIONS - 100 YEAR EVENT

PATH: S:\SR108\MP5.5 WDFW ID 991237 UNT TO SKOOKUM\RESULTS\OUTPUT FIGURES\PROPOSED_100YR FINAL.MXD - USER: DMINNER - DATE: 10/2/2019

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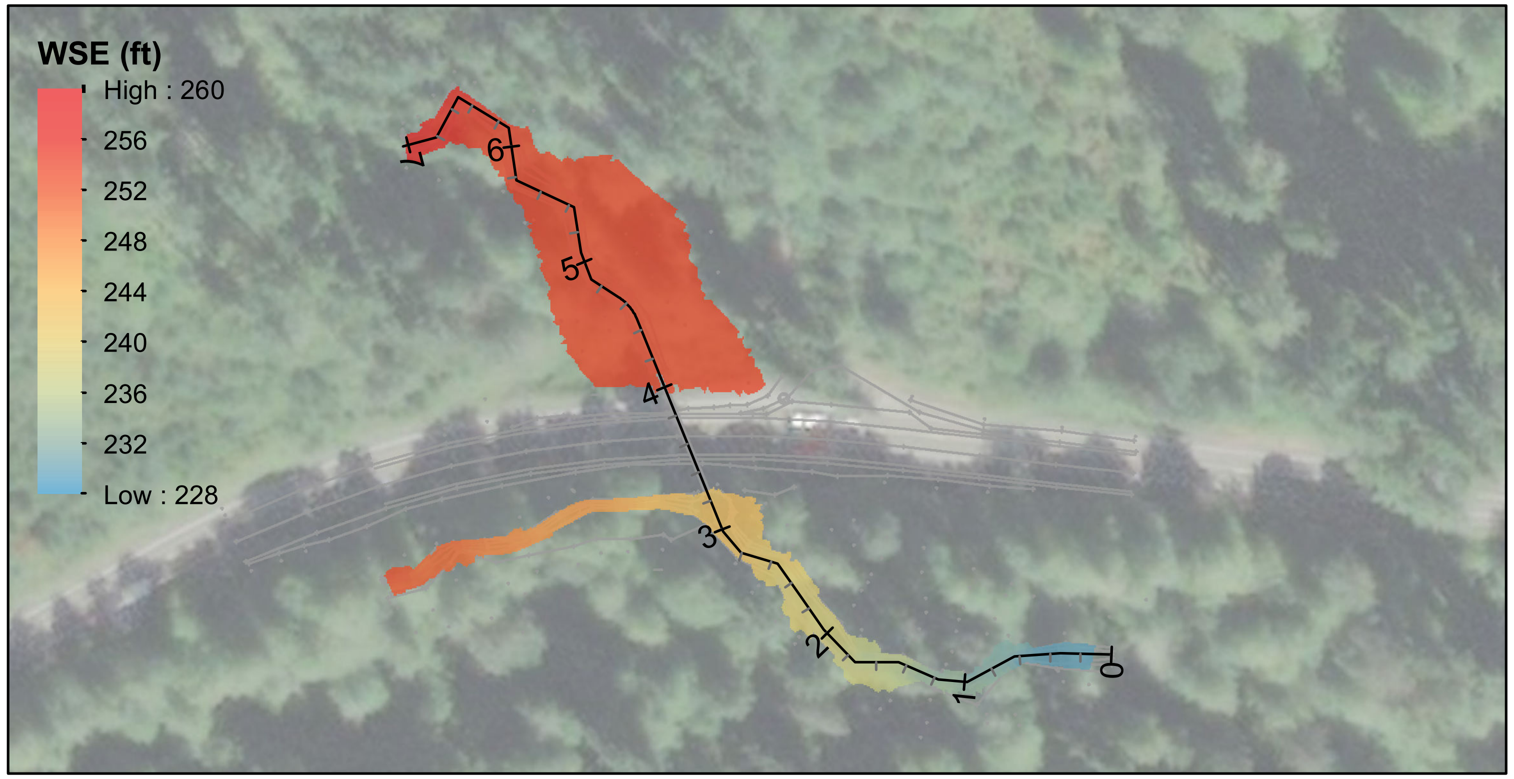
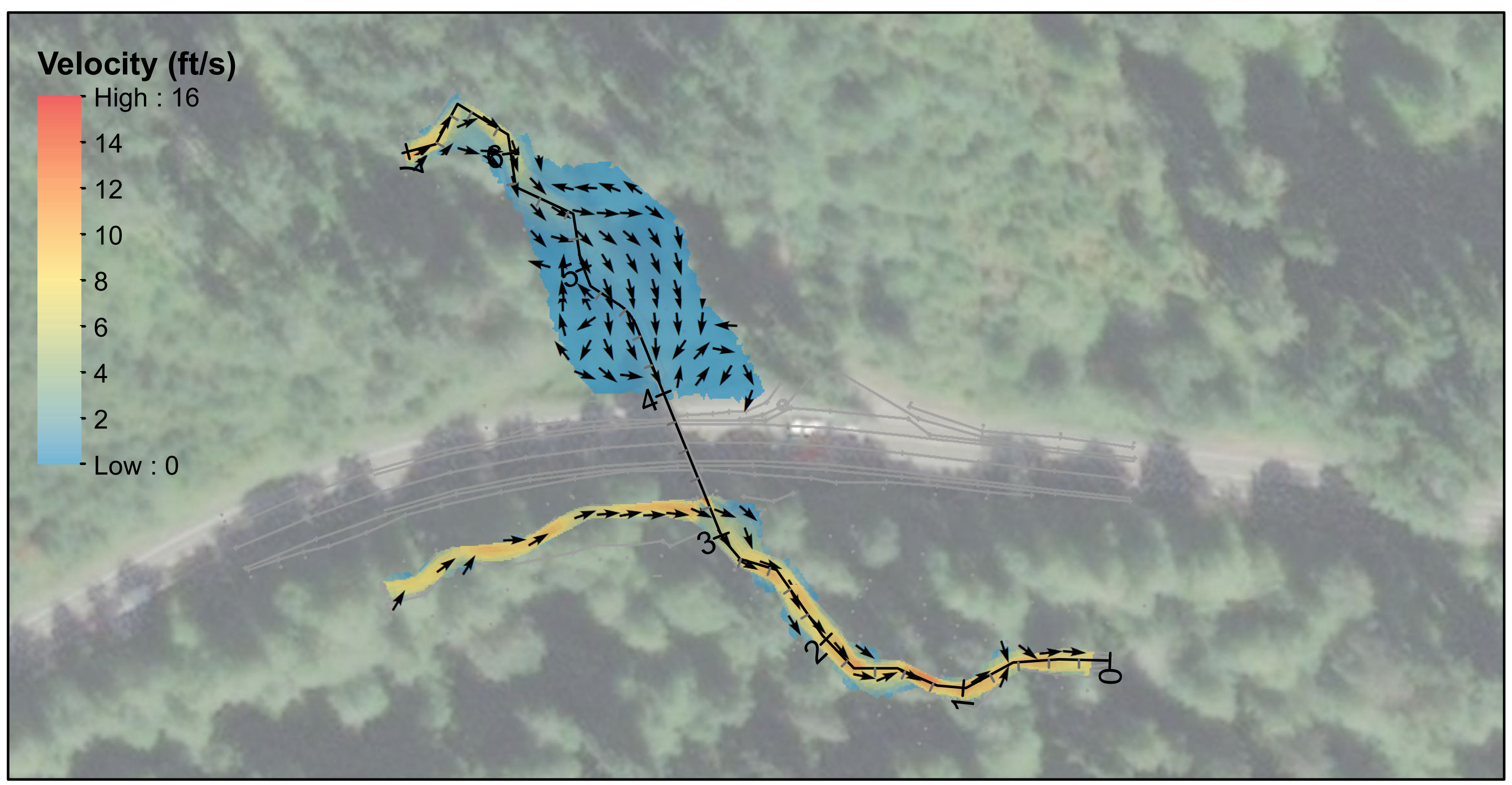


WATER SURFACE ELEVATION

DEPTH



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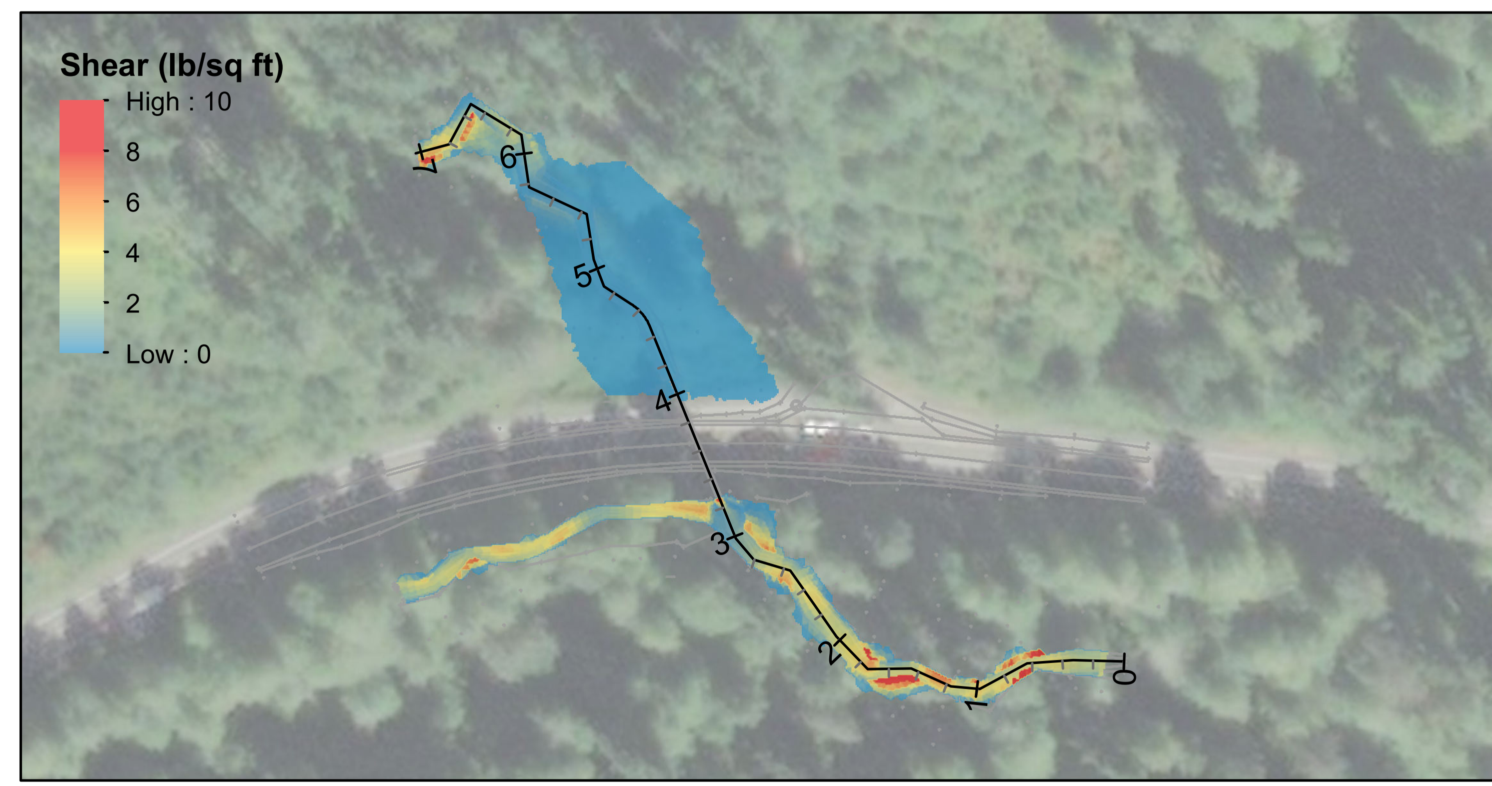


SHEAR

N

0 75 150 Feet

HDR

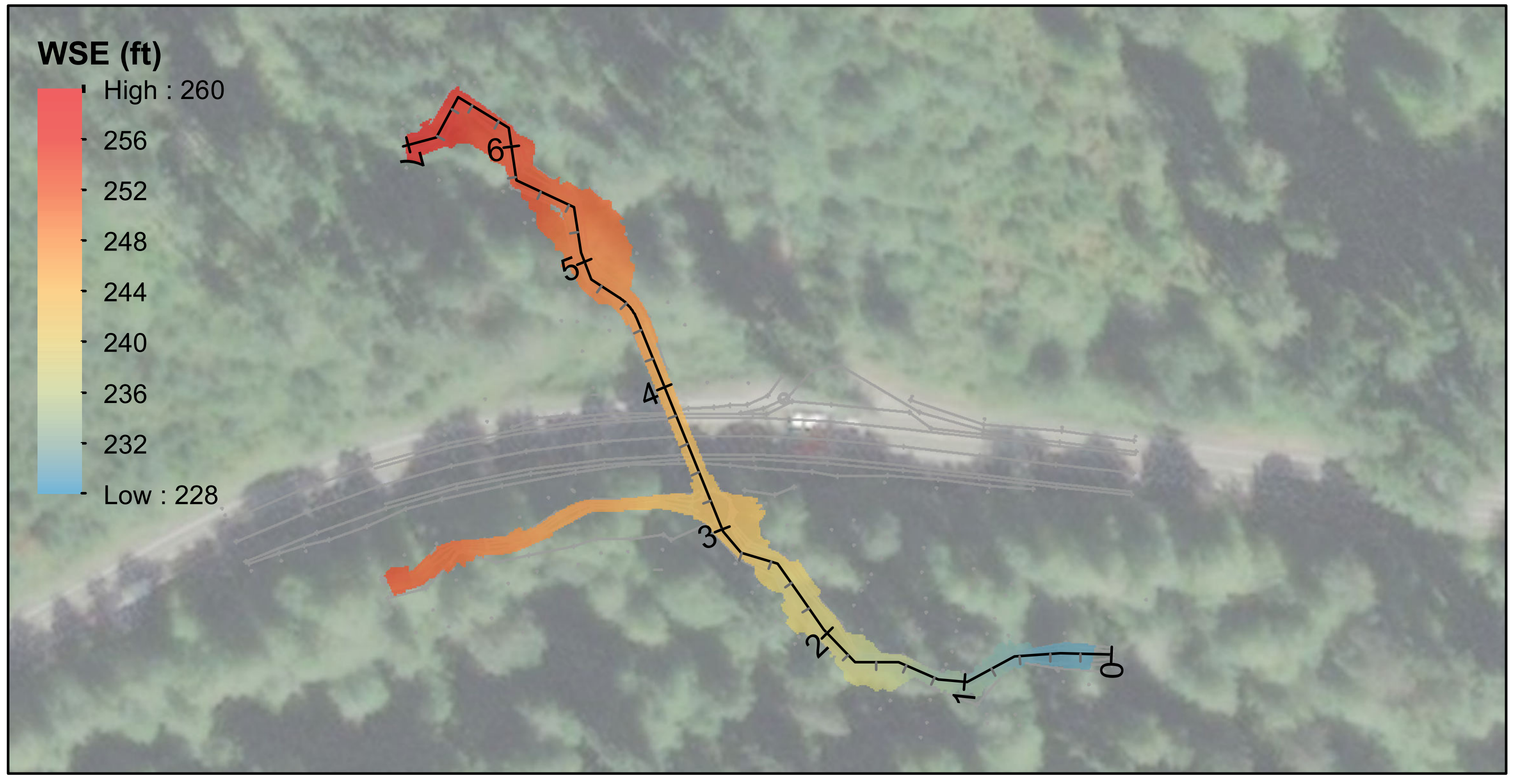
Washington State Department of Transportation

EXISTING CONDITIONS - 500 YEAR EVENT

SR 108 UNNAMED TRIBUTARY TO SKOOKUM
MP 5.5

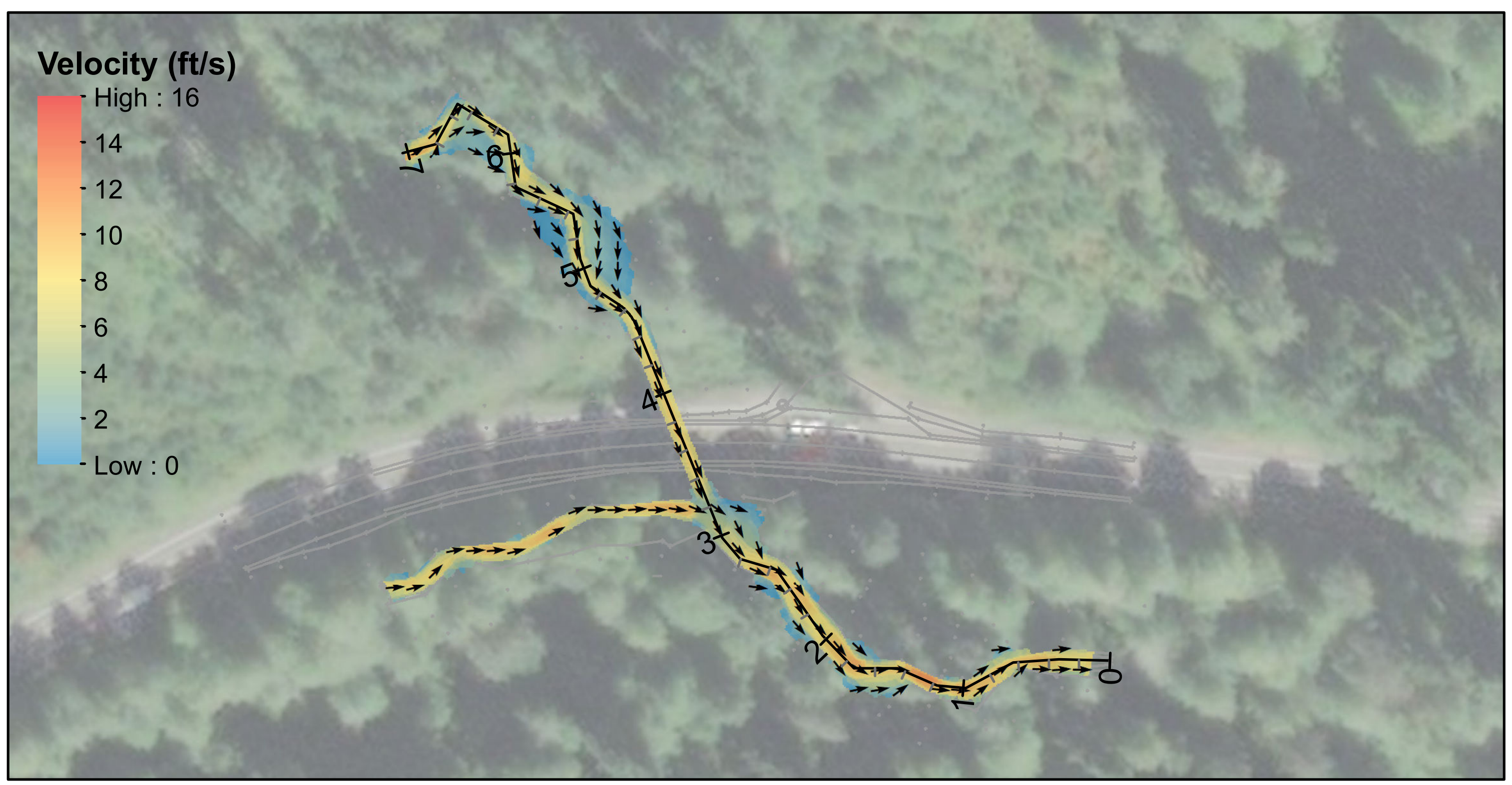
PATH: S:\SR108\MP5.5 WDFW ID 991237 UNT TO SKOOKUM\RESULTS\OUTPUT FIGURES\EXISTING_500YR FINAL.MXD - USER: DMINNER - DATE: 10/2/2019

PRELIMINARY HYDARULIC DESIGN



WATER SURFACE ELEVATION

DEPTH



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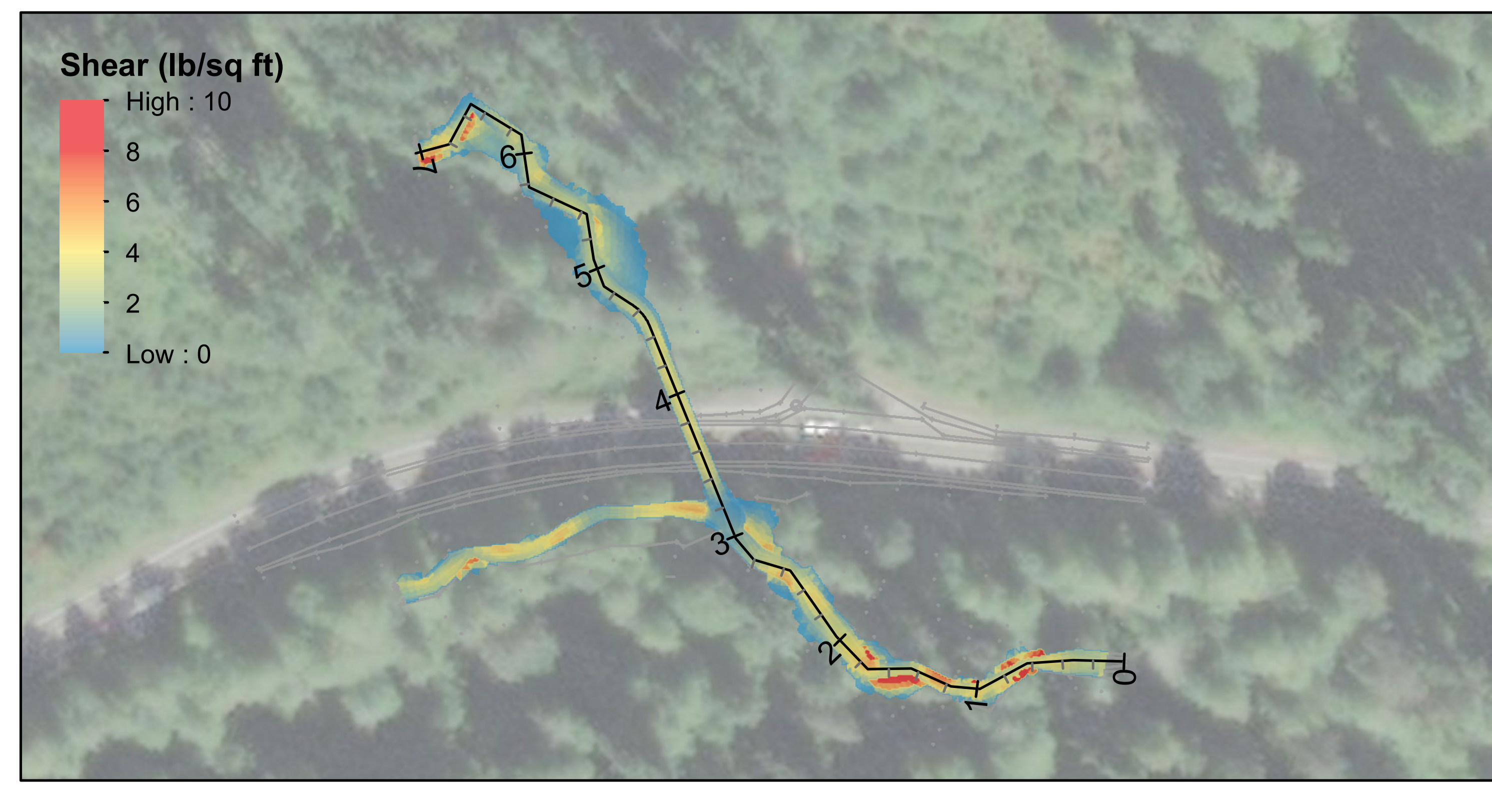


SHEAR

N

0 75 150 Feet

Washington State Department of Transportation

PROPOSED CONDITIONS - 500 YEAR EVENT

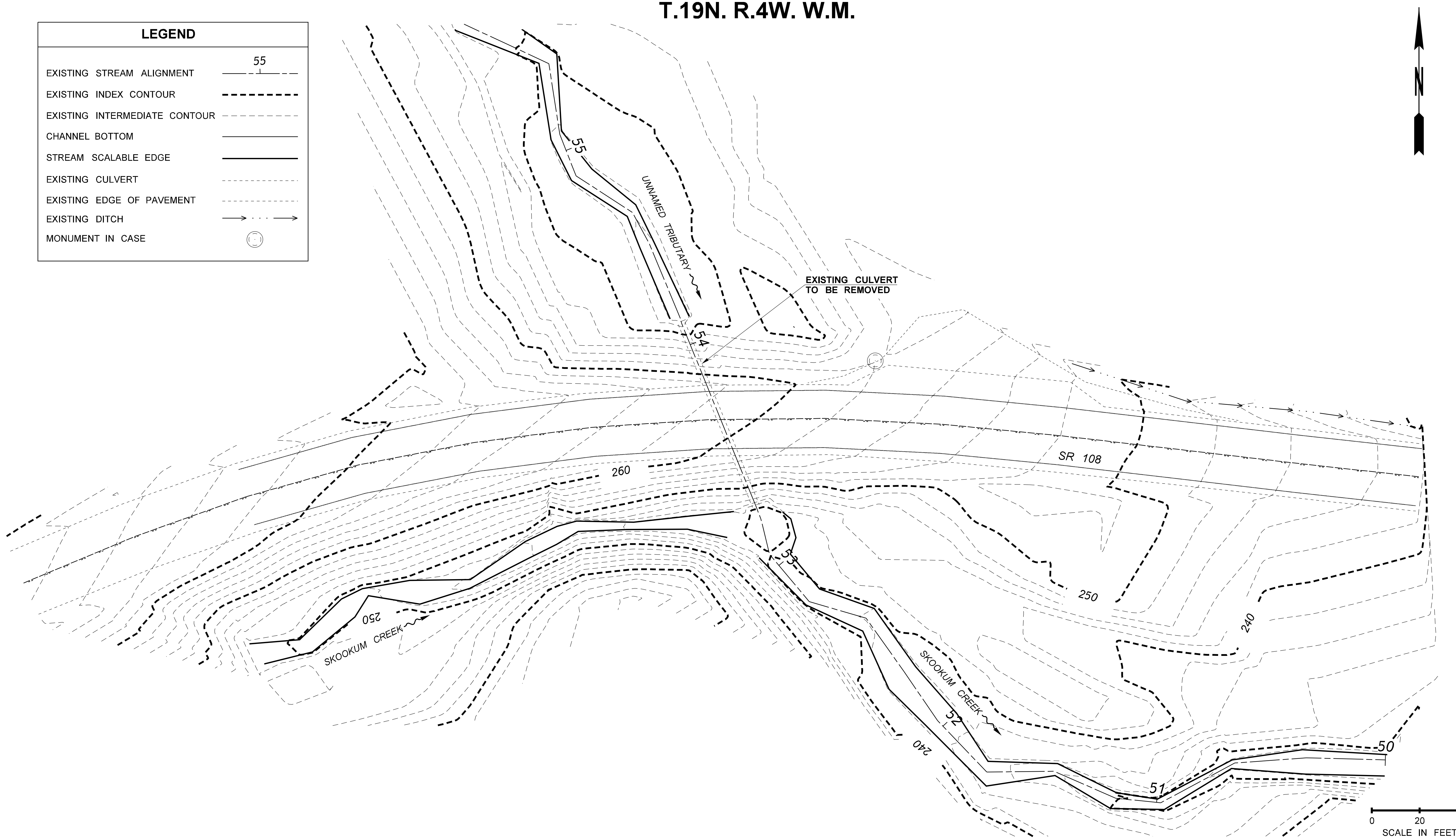
SR 108 UNNAMED TRIBUTARY TO SKOOKUM
MP 5.5

PATH: S:\SR108\MP5.5 WDFW ID 991237 UNT TO SKOOKUM\RESULTS\OUTPUT FIGURES\PROPOSED_500YR FINAL.MXD - USER: DMINNER - DATE: 10/2/2019

PRELIMINARY HYDARULIC DESIGN

Appendix B – Stream Plan Sheets, Profile, Details

T.19N. R.4W. W.M.



PRELIMINARY - NOT FOR CONSTRUCTION

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DATE	10/2/2019
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DESIGNED BY	S. BEVAN
ENTERED BY	C. WILCOX
CHECKED BY	J. HEILMAN
PROJ. ENGR.	J. METTLER
REGIONAL ADM.	J. WYNANDS

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL5950

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

HDR

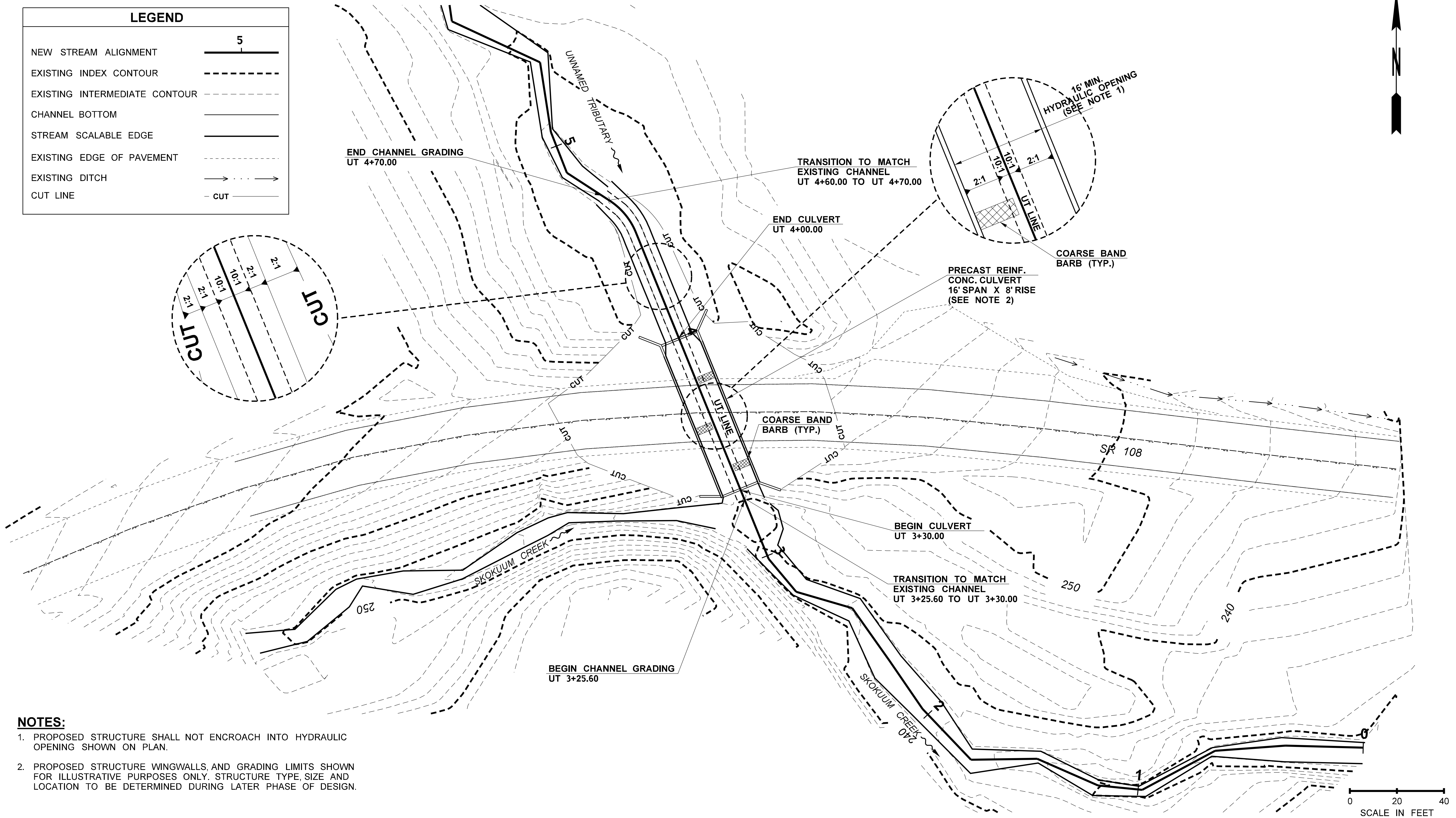
SR 108
MP 5.5
SKOOKUM CREEK TRIBUTARY

EXISTING STREAM PLAN

PLAN REF NO CE1

SHEET 1 OF 4 SHEETS

T.19N. R.4W. W.M.



NOTES:

1. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO HYDRAULIC OPENING SHOWN ON PLAN.
2. PROPOSED STRUCTURE WINGWALLS, AND GRADING LIMITS SHOWN FOR ILLUSTRATIVE PURPOSES ONLY. STRUCTURE TYPE, SIZE AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN.

PRELIMINARY - NOT FOR CONSTRUCTION

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DATE	10/2/2019
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DESIGNED BY	S. BEVAN
ENTERED BY	C. WILCOX
CHECKED BY	J. HEILMAN
PROJ. ENGR.	J. METTLER
REGIONAL ADM.	J. WYNANDS

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL5950

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

HDR

SR 108
MP 5.5
SKOOKUM CREEK TRIBUTARY

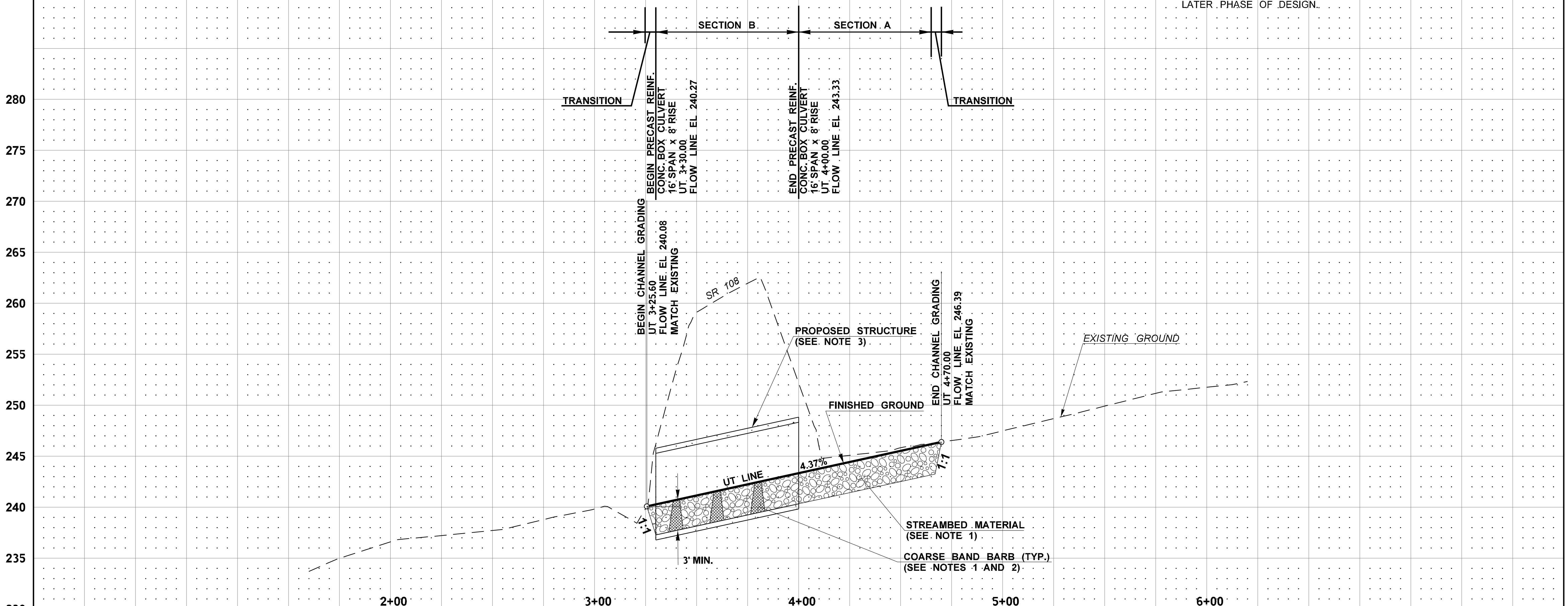
STREAM PLAN

PLAN REF NO CR1

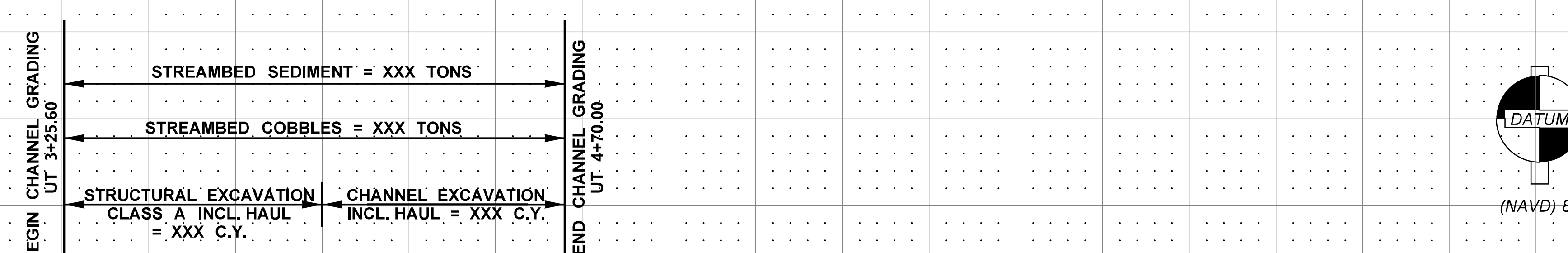
SHEET 2 OF 4 SHEETS

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES FOR STREAMBED MATERIALS.
2. SEE SHEET CD1 FOR STREAM SECTIONS.
3. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY, STRUCTURE TYPE, SIZE, AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN.



UT LINE PROFILE



PRELIMINARY - NOT FOR CONSTRUCTION

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DESIGNED BY	S. BEVAN			
ENTERED BY	C. WILCOX			
CHECKED BY	J. HEILMAN			
PROJ. ENGR.	J. METTLER			
REGIONAL ADM.	J. WYNANDS	REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL5950

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

Washington State Department of Transportation

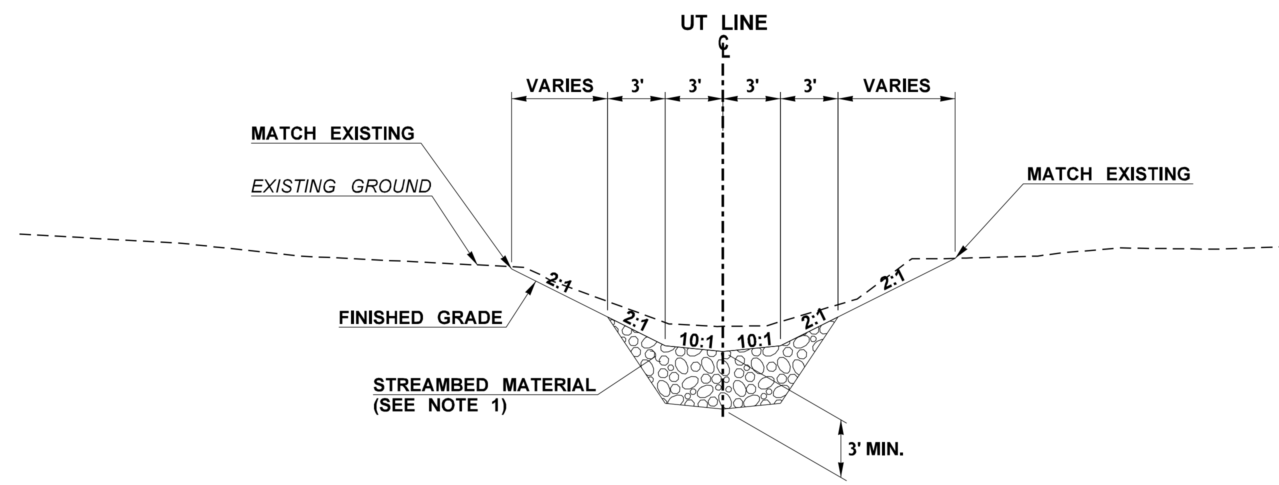
HDR

SR 108
MP 5.5
SKOOKUM CREEK TRIBUTARY

STREAM PROFILE

PLAN REF. NO. CP1

SHEET 3 OF 4 SHEETS



SECTION A

STATION
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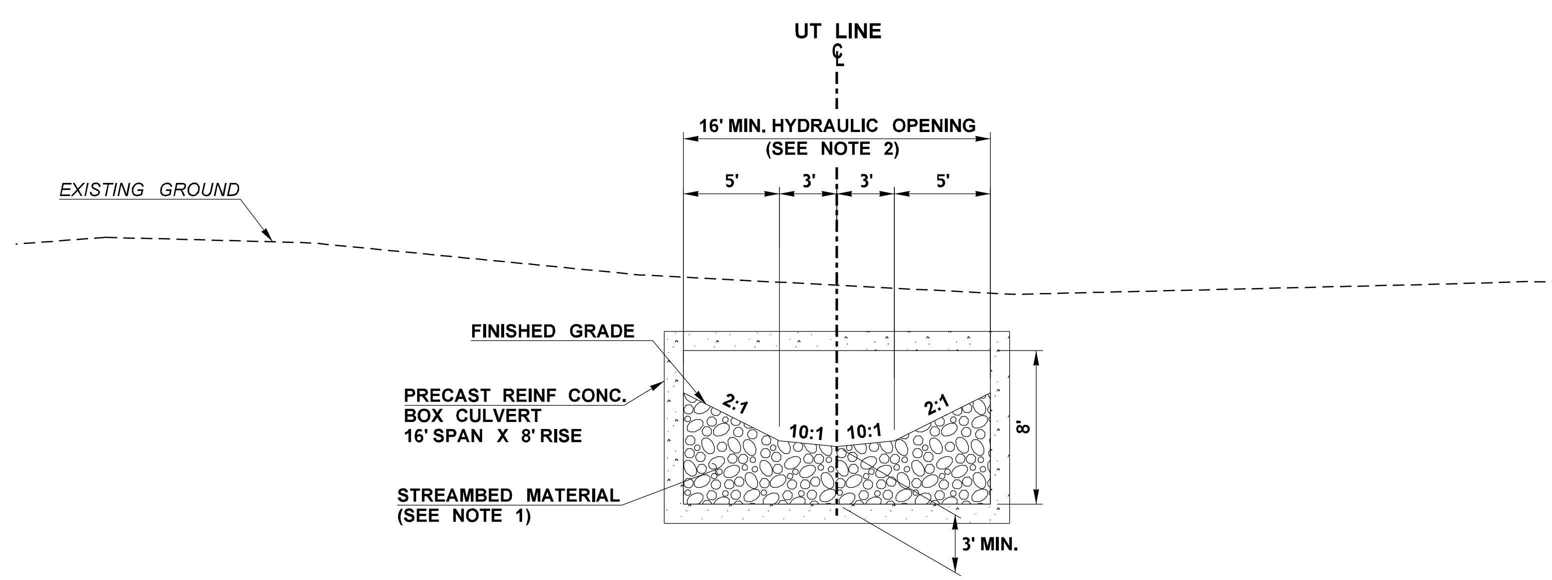

SECTION B

STATION
UT 3+30.00 TO 4+00.00

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATE FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL.
2. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO MINIMUM OPENING SHOWN ON PLAN.

PRELIMINARY - NOT FOR CONSTRUCTION

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PROJ. ENGR.	J. METTLER
REGIONAL ADM.	J. WYNANDS

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL5950

P.E. STAMP BOX DATE

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STREAM DETAILS

PLAN REF NO CD1

SHEET 4 OF 4 SHEETS

Appendix C – WDFW Future Projections for Climate-Adapted Culvert Design Printout

Future Projections for Climate-Adapted Culvert Design

Project Name:	991237
Stream Name:	
Drainage Area:	153 ac

Projected mean percent change in bankfull flow:

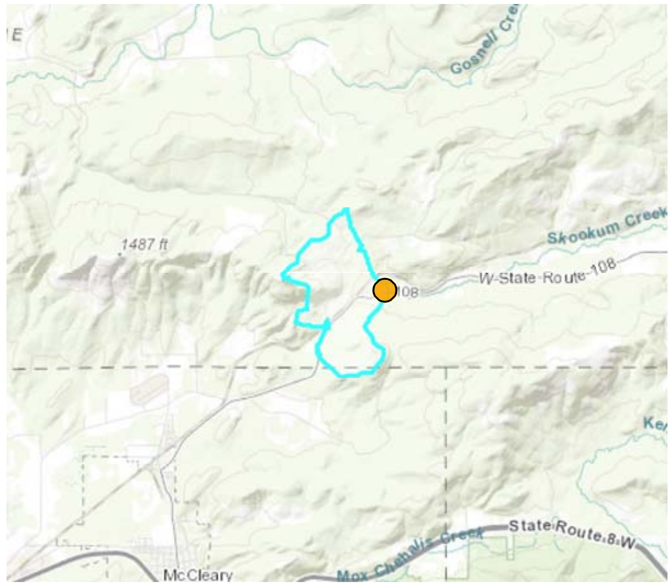
2040s:	15%
2080s:	21.7%

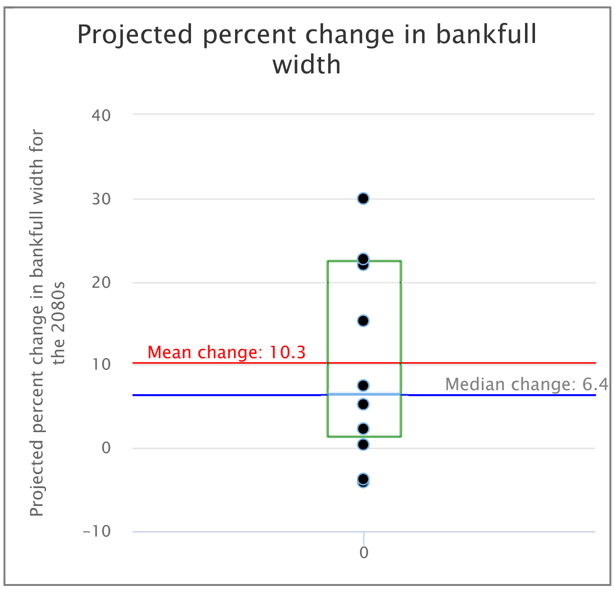
Projected mean percent change in bankfull width:

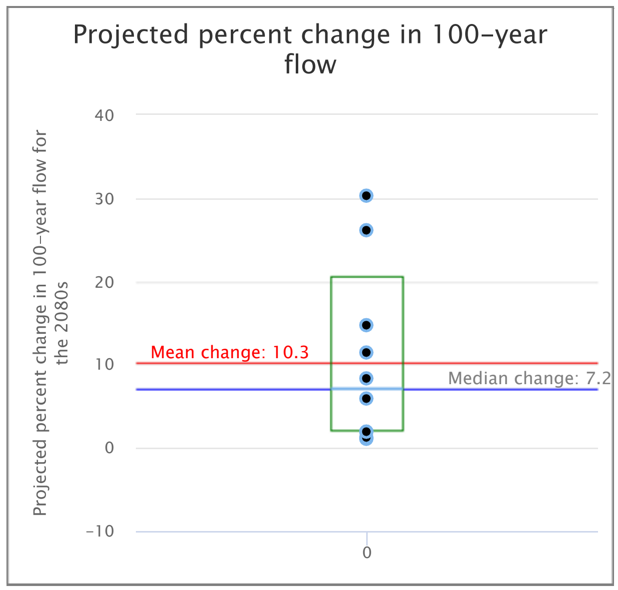
2040s:	7.2%
2080s:	10.3%

Projected mean percent change in 100-year flood:

2040s:	3.7%
2080s:	10.3%







Black dots are projections from 10 separate models

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